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Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme (WP 10317)

INTERMEDIATE RESERVE DETERMINATION REPORT

FEBRUARY 2014

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Project name:	***Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme***
Report Title:	***Intermediate Preliminary Reserve Determination***
Author:	***S Koekemoer and river team***
Editor:	***P-A Scherman (Scherman Colloty & Associates)***
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* *BKS (Pty) Ltd was acquired by AECOM Technology Corporation on 1 November 2012*

LIST OF STUDY REPORTS

This report forms part of the series of reports, prepared for the Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme. All reports for the Study are listed below.

Report Name	**DWA Report Number**
Water Resources Assessment	P WMA 12/T60/00/3711
Assessment of Augmentation from Groundwater	P WMA 12/T60/00/3811
Intermediate Preliminary Reserve Determination	***P WMA 12/T60/00/3911***
Legal, Institutional and Financial Arrangements	P WMA 12/T60/00/4011
Domestic Water Requirements	P WMA 12/T60/00/4111
Irrigation Potential Assessment	P WMA 12/T60/00/4211
Water Distribution Infrastructure	P WMA 12/T60/00/4311
Materials and Geotechnical Investigations	P WMA 12/T60/00/4411
Zalu Dam Feasibility Design	P WMA 12/T60/00/4511
Regional Economics	P WMA 12/T60/00/4611
Environmental Screening	P WMA 12/T60/00/4711
Record of Implementation Decisions	P WMA 12/T60/00/4811
Main Study Report	P WMA 12/T60/00/4911

This report is to be referred to in bibliographies as:

Department of Water Affairs, 2014. FEASIBILITY STUDY FOR AUGMENTATION OF THE LUSIKISIKI REGIONAL WATER SUPPLY SCHEME: INTERMEDIATE PRELININARY RESERVE DETERMINATION, P WMA 12/T60/00/3911

Prepared by:

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Team Member: Specialization	Company Name
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Louw, MD: Habitat integrity and EWR integrator/coordinator	Rivers for Africa
Birkhead, A: Hydraulics	Streamflow Solutions
Van Niekerk, E: Hydrology and yield modelling	AECOM
Rountree, M: Geomorphology	Fluvius Consulting
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Koekemoer, S: Diatoms	Koekemoer Aquatic Services

Executive summary

BACKGROUND

During 2010 BKS (now AECOM) was appointed by the Department of Water Affairs: Eastern Cape (DWA: EC) to conduct the Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme. Module 4 of this study is being coordinated by Scherman Colloty & Associates, and encompasses a task on the determination of Ecological Water Requirements (EWR, or the Intermediate Ecological Reserve) for the system under investigation, i.e. the Xura and Msikaba rivers, following the 8-step methodology currently in place for Reserve determinations.

STUDY AREA AND LOCATION OF EWR SITES

*The locality of the EWR sites within the Management Resource Units (MRUs) identified for the study is provided in **Table i**.*

Table i: Locality and characteristics of EWR site

EWR site	River	Co-ordinates		EcoRegion (Level II)	Geozone[1]	Altitude (masl)	MRU	Quat[2]	Gauge
		Latitude	Longitude						
EWR 1	Xura	-31.327°	29.48686°	16.03	Lower Foothills	586	MRU 1: From source to T6H004	T60F	T6H004
EWR 2	Msikaba	-31.251750°	29.748850°	17.01	Lower Foothills	208	MRU 2: Represented by T60G_06145 (**Figure 1.2**)	T60G	none

1: Geomorphological zone *2: Quaternary catchment*

APPROACHES AND METHODS

As indicated in the Terms of Reference, EWRs were determined applying the Intermediate Ecological Reserve Methodology (DWAF, 1999). The methodology consists of two different steps:

- *EcoClassification; and*
- *EWR quantification for different ecological states.*

The EcoClassification process was followed according to the methods of Kleynhans and Louw (2007). EcoClassification refers to the determination and categorisation of the Present

Ecological State (health or integrity) of various biophysical attributes of rivers compared to the natural (or close to natural) reference condition. The state of the river is expressed in terms of biophysical components:

- *Drivers (physico-chemical, geomorphology, hydrology), which provide a particular habitat template; and*
- *Biological responses (fish, riparian vegetation and macroinvertebrates).*

Different processes are followed to assign a category (A →F; A = Natural, and F = Critically Modified) to each component. Ecological evaluation in terms of expected reference conditions, followed by integration of these components, represents the Ecological Status or EcoStatus of a river.

The Habitat Flow Stressor Response method (IWR S2S, 2004; O'Keeffe et al., 2002), a modification of the Building Block Methodology (BBM; King and Louw, 1998) was used to determine the low (base) flow EWR. This is one of the methods used to determine the EWR at an intermediate level.

The approach to set high flows is a combination of the Downstream Response to Imposed Flow Transformation (DRIFT; Brown and King, 2001) approach and the BBM.

ECOCLASSIFICATION RESULTS

The results of the EcoClassification process are summarised in ***Table ii****. See electronic data for models.*

The confidence in the EcoClassification process is provided in ***Table iii*** *and was based on the following:*

- *Data availability: Evaluation based on the adequacy of any available data for interpretation of the Ecological Category (EC) and Alternative Ecological Category (AEC).*
- *Process: Evaluation based on the confidence in the outcome and probable accuracy in defining the Present Ecological State (PES).*

Table ii: EcoClassification results summary

EWR 1

EIS: MODERATE
Highest scoring of the metrics used to assess EIS were unique instream species, diversity of instream and riparian habitat types, presence of critical instream refuges and important riparian migration corridors.

PES: B
Trampling and limited erosion (cattle).
Increased nutrient levels (cattle, human waste and clothes washing).
Alien vegetation.

REC: B
EIS was MODERATE and the REC was therefore to maintain the PES.

AEC: C
A hypothetical deteriorated situation was characterised by decreased flows and the resulting abitic and biotic responses to this situation.

Driver Components	PES & REC	Trend	AEC ↓
IHI HYDROLOGY	A/B		
WATER QUALITY	A/B		B/C
GEOMORPHOLOGY	A/B		C
Response Components	**PES**	**Trend**	**AEC↑**
FISH	A/B	0	B/C
MACRO INVERTEBRATES	A/B	0	B/C
INSTREAM	A/B	0	B/C
RIPARIAN VEGETATION	B/C	0	C
ECOSTATUS	B		C
INSTREAM IHI	A/B		
RIPARIAN IHI	B		
EIS	MODERATE		

EWR 2

EIS: MODERATE
Highest scoring of the metrics used to assess EIS were unique instream species, presence of critical instream refuges and important instream and riparian migration corridors.

PES: B/C
Trampling and limited erosion (cattle).
Increased nutrient levels (cattle, discharges from upstream Water Treatment Works and Holycross Hospital).
Alien vegetation.

REC: B/C
EIS was MODERATE and the REC was therefore set to maintain the PES.

AEC: C/D
A hypothetical deteriorated situation was characterised by decreased flows and the resulting abiotic and biotic response to this situation.

Driver Components	PES & REC	Trend	AEC↓
IHI HYDROLOGY	A/B		
WATER QUALITY	B		C
GEOMORPHOLOGY	A		B
Response Components	**PES**	**Trend**	**AEC↓**
FISH	A/B	0	B/C
MACRO INVERTEBRATES	B	0	C
INSTREAM	B	0	C
RIPARIAN VEGETATION	C	0	C/D
ECOSTATUS	B/C		C
INSTREAM IHI	B		
RIPARIAN IHI	B/C		
EIS	MODERATE		

The confidence score is based on a scale of 0 – 5 and colour coded thus:

0 – 1.9: Low   *2 – 3.4: Moderate*   *3.5 – 5: High*

These confidence ratings are applicable to all scoring provided in the report.

Table iii: Confidence in EcoClassification

EWR site	Data availability									EcoClassification								
	Hydrology	Water Quality	Geomorph	IHI	Fish	Macro-invertebrates	Vegetation	Average	Median	Hydrology	Water Quality	Geomorp	IHI	Fish	Macro-invertebrates	Vegetation	Average	Median
EWR 1 (Xura)	3	3	2	3.1	3	2.5	3	2.8	3	4	4	4	3.1	4	3	3	3.6	4.0
EWR 2 (Msikaba)	2	2.5	3	3.5	2	3	2	2.6	2.5	4	3	4	3.5	2	3	3	3.2	3.0

The results indicated an overall Moderate to High confidence. The higher confidence at EWR 1 was related to the presence of the gauging weir with available hydrology and the availability of water quality data.

ECOLOGICAL WATER REQUIREMENTS

*A summary of the final flow results are provided in **Table iv** as a percentage of the natural (or virgin) Mean Annual Runoff (MAR) and the volumes.*

Table iv: Summary of results as a percentage of the natural MAR

EWR site	Ecological Category (EC)	Maintenance low flows		Drought low flows		High flows		Long term mean	
		% nMAR	million m³	% nMAR	million m³	% nMAR	million m³	% nMAR	million m³
EWR 1	PES and REC: A/B	22.49	3.186	5.70	0.807	20.21	2.863	36.79	5.212
	AEC: B/C	16.19	2.294	4.75	0.673	14.19	2.009	28.71	4.067
EWR 2	PES and REC: B	18.37	23.684	9.96	12.837	12.98	16.687	30.08	38.792
	AEC: C	13.25	17.09	8.34	10.751	7.42	9.565	22.88	29.457

*The overall confidence (**Table v**) in the results are linked to the confidence in the hydrology and hydraulics as the hydrology provides the check and balance of the results and the hydraulics converts the requirements in terms of hydraulic parameters to flow. Therefore, the following rationale was applied when determining the overall confidence:*

- *If the hydraulics confidence was lower than the biological responses column, the hydraulics confidence determined the overall confidence. Hydrology confidence was also considered, especially if used to guide the requirements.*
- *If the biological confidence was lower than the hydraulics confidence, the biological confidence determined the overall confidence. Hydrology confidence was also considered.*

If hydrology was used to guide requirements, then that confidence would be overriding in determining the overall confidence.

Table v: Overall confidence in EWR results

Site	Hydrology	Biological responses : Low flows	Hydraulic: Low Flows	OVERALL: LOW FLOWS	COMMENT	Biophysical responses: High flows	Hydraulics: High Flows	OVERALL: HIGH FLOWS	COMMENT
EWR 1	2.8	3	3	**3**	*The drought flows were of moderate confidence as the EWRs were lower than the measured flow and the site was complex. There were uncertainties with the flow class modelling. The maintenance flows were rated as a 5 confidence as the range of EWRs were close to the flows requested.*	3.5	2	**2**	*Flows were above measured flow range. High flow strand data, but above rating for local gauge.*
EWR 2	1.8	3.5	3	**3**	*Flows were below the minimum measured.*	2.25	2	**2**	*Above measured flow range. Uncertainty in high flow slopes (non-uniform flows due to upstream/downstream pools).*

OPERATIONAL SCENARIOS

The latest version of the Water Resource Yield Model (WRYM) incorporated in the Water Resource Information Management System (WRIMS), version 3.8.2, was used to simulate the behaviour of the Xura River and the water users under various development scenarios. Scenarios to reflect the most probable future developments were created in consultation with DWA and are shown in ***Table vi*** *below. Scenario selection was an iterative process, with the scenarios selected for the ecological consequences analyses only investigating domestic releases via the river. This was based on yield analyses demonstrating the benefit of releases from the dam and abstraction from the weir. Irrigation abstraction was assumed to be directly from Zalu Dam.*

Table vi: Proposed scenarios to determine the ecological consequences of the proposed developments

Scenario	*Zalu Dam 607.5m 4.89 million m^3*	*Zalu Dam 610.2m 6.53 million m^3*	*Zalu Dam 611.5m 7.64 million m^3*	*Zalu Dam 614.48m 10.19 million m^3*	*Domestic abstraction at T6H004 million m^3/a*	*Irrigation direct from Zalu dam million m^3/a*
1	√				*4.47*	
2		√			*5.40*	
3			√		*4.47*	*1.452*
4				√	*5.40*	*1.452*

Note that Scenarios 2 and 3 are very similar, with insufficient resolution to distinguish between them in terms of ecological impact. The analyses reflect on the flow in the river relating to the proposed development scenarios to study the impact thereof if no water at all is implicitly released to meet the Reserve requirements. Ecological consequences of scenarios are discussed in this document.

Yield modelling indicated that the <u>EWR are met at all reaches during the dry season</u>, however a number of concerns are raised by the ecologists and are addressed in Chapter 6.

*The total annual **volume** specified for floods at EWR 1 according to the Intermediate Preliminary Reserve determination is 2.86 million m^3/a. A summary of the spill analyses shows that the <u>total annual volume of spills exceeds the flood requirement of the EWR, but compliance with specific monthly volumes decreases from 62% to 47%.</u> Implications for geomorphology and riparian vegetation are discussed in Chapter 6.*

RECOMMENDATIONS / MONITORING

EWR 1: Improvement in the confidence of the biotic components can be achieved through sampling at a wider range of river flows than were possible during this Study. These flows should ideally include lower flows than those measured. Sampling in September 2011 and February 2012 respectively was conducted at flows of:

- *EWR 1: 0.16 and 0.12 m^3/s*
- *EWR 2: 1.2 and 1.3 m^3/s*

Flow monitoring could form part of an Integrated Water Resources Monitoring (IWRM) programme. An improvement in hydraulic confidence could be achieved by obtaining a calibration in the region of the recommended drought flows and during a flood.

EWR 2: The lack of flow variability measured during the study was similar to that experienced at EWR 1 and future monitoring should aim to improve low flow confidences. It is strongly recommended that an Ecological Water Resources Monitoring (EWRM) programme is initiated as soon as possible. The information gathered during this study is suitable for determining baseline conditions, but if too much time (> 5 years) lapses between the collected baseline data and the implementation of monitoring, and it can be shown that there have been significant changes in the catchment, new surveys and the application of the EcoClassification process may have to be undertaken.

Monitoring recommendations are made in the form of Ecological Specifications (EcoSpecs) and Thresholds of Probable Concern (TPCs) per component, and presented in Chapter 11.

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List of abbreviations

AEC(s)	Alternative Ecological Categories
AEG	Acute Effects Value
AVE	Average
BBM	Building Block Methodology
BFI	Base-flow Index
Conf	Confidence
DL EWR	Drought low flow EWR
D: NWRP	Directorate: National Water Resource Planning
DO	Dissolved Oxygen
D: RQS	Directorate: Resource Quality Services
DRIFT	Downstream Response to Imposed Flow Transformation
DRM	Desktop Reserve Model
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWA: EC	Department Water Affairs: Eastern Cape

DWA: EC RHP	Department Water Affairs: Eastern Cape River Health Programme
EC(s)	Ecological Categories
EIA	Environmental Impact Assessment
EIS	Ecological Importance and Sensitivity
EPBS	Eastern Pondoland Basin Study
EWR	Ecological Water Requirements
EWRM	Ecological Water Resources Monitoring
FDI	Flow Dependent Invertebrates
FDT	Flow Duration Table
FFHA	Fish Flow Habitat Assessment
FRAI	Fish Response Assessment Index
FROC	Frequency of Occurrence
GAI	Geomorphological Driver Assessment Index
Geom	Geomorphology
Geozone	Geomorphological zone
HFSR	Habitat Flow Stressor Response
Hydro	Hydrology
IERM	Intermediate Ecological Reserve Methodology
IHI	Index of Habitat Integrity
Inverts	Macroinvertebrates
IWRM	Integrated Water Resources Monitoring
LRWSS	Lusikisiki Regional Water Supply Scheme
LSR	Large semi-rheophilics
MAR	Mean Annual Runoff
MH EWR	Maintenance high flow EWR
MIRAI	Macroinvertebrate Response Assessment Index
ML EWR	Maintenance low flow EWR
MRUs	Management Resource Units
MV	Marginal Vegetation
MVI	Marginal Vegetation Invertebrates
NF	Non-Flow
PAI	Physico-chemical Driver Assessment Index
PES	Present Ecological State
POSA	Plants of South Africa
Quat	Quaternary catchment

RC	Reference Condition
REC(s)	Recommended Ecological Categories
RSA	Republic of South Africa
RHP	River Health Programme
Rip veg	Riparian vegetation
RU	Resource Unit
SASS5	South African Scoring System version 5
SPATSIM	Spatial and Time Series Modelling
SPI	Specific Pollution tolerance Index
TEACHA	Tool for Ecological Aquatic Chemical Habitat Assessment
TIN	Total Inorganic Nitrogen
TPCs	Thresholds of Probably Concern
TWQR	Target Water Quality Range
VEGRAI	Riparian Vegetation Response Assessment Index
WRC	Water Research Commission
WRYM	Water Resource Yield Model
WRIMS	Water Resource Information Management System
WTW	Water Treatment Works

Fish Hydraulic biotopes:

FD	Fast-Deep
FS	Fast-Shallow
SD	Slow-Deep
SS	Slow-Shallow
FI	Fast Intermediate

Macroinvertebrate hydraulic biotopes:

FBR	Fast over bedrock
FCS	Fast over coarse substrate
VFBR	Very fast over bedrock
VFCS	Very fast over coarse substrate

List of units

km	kilometre
m	metre
masl	meters above sea level
million m^3	million cubic metres
m^3/s	cubic metre per second
NTU	nephelometric turbidity units

1 INTRODUCTION

The Department of Water Affairs (DWA) appointed BKS (Pty) Ltd in association with four sub-consultants (**Africa Geo-Environmental Services, KARIWA Project Engineers & Associates, Scherman Colloty & Associates and Urban-Econ**) with effect from 1 September 2010 to undertake the **Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme**.

On 1 November 2012, BKS (Pty) Ltd was acquired by AECOM Technology Corporation. The new entity has the same company registration number as that of BKS. As a result of the change in name and ownership of the company during the study period, all the final study reports will be published under the AECOM name.

1.1 BACKGROUND TO THE PROJECT

In the 1970s Consultants O'Connell Manthé and Partners and Hill Kaplan Scott recommended that a regional water supply scheme based on a dam on the Xura River and a main bulk supply reservoir close to Lusikisiki (located within the then defined "administration area" of the Zalu Dam) would provide potable water supply for the entire region between Lusikisiki and the coast, extending from the Mzimvubu River in the south west to the Msikaba River in the north east. Some areas up to 15 km inland of Lusikisiki would also be supplied. A White Paper describing the scheme was tabled by the Transkei Government in 1979. It was envisaged that the scheme would be constructed in phases. Details of the proposed phasing of the scheme are provided in *Lusikisiki Regional Water Supply: Preliminary Report* (Hill Kaplan Scott, 1986).

After the reincorporation of the Transkei Homeland into the Republic of South Africa (RSA) in 1994, the DWA took over responsibility for further development of the scheme. The Directorate: National Water Resource Planning (D: NWRP) commissioned the Eastern Pondoland Basin Study (EPBS) in 1999 to further investigate the water supply situation in the area, with a specific focus on further development in the area originally earmarked for the Lusikisiki Regional Water Supply Scheme (LRWSS). This detailed investigation was undertaken for surface and groundwater resources, which reaffirmed that the Zalu Dam was the preferred source of surface water and recommended further investigation of groundwater sources to augment water supply to the entire area or to sub-areas.

In 2007, SRK Consulting undertook the Lusikisiki Groundwater Feasibility Study to investigate groundwater potential and compare the new data with data produced by earlier studies. This study reported that there is a relatively strong possibility of finding high yielding boreholes, and that a combination of surface water (Zalu Dam) and groundwater would be the most feasible solution for the LRWSS.

1.2 STUDY AREA

The study area comprises the entire region between Lusikisiki (up to about 15 km inland) and the coast, extending from the Mzimvubu River in the south-west to the Msikaba River in the north-east. This area includes the Zalu Dam site (and associated catchment) in the Xura River and the selected conveyance routes between the dam and the extended supply area. It also includes the boreholes to be selected for augmentation and the routes of the pipelines to augment the water supply to the users.

During the Inception Phase the study area was extended in the vicinity of the Zalu Dam and to the north of Lusikisiki, as agreed with the DWA and as indicated on Figure 1.1. In the south-western part of the study area the main focus will be on water supply from groundwater, due to the distance from the surface water source, Zalu Dam, as well as unfavourable topography.

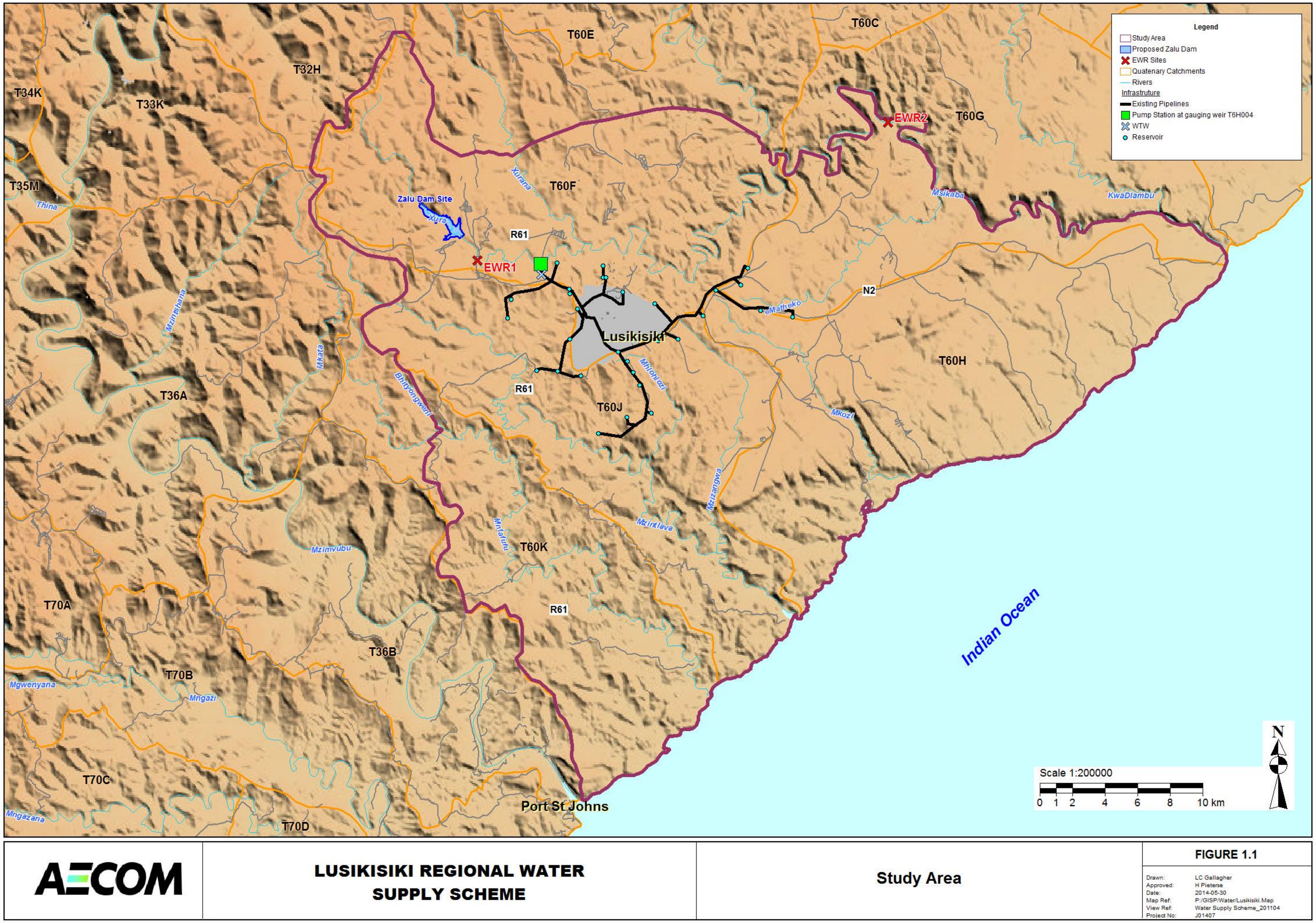

Figure 1.1: Study area

1.3 OBJECTIVE, SCOPE AND ORGANISATION OF THE FEASIBILITY STUDY

The objective of this study is to complete a comprehensive engineering investigation at feasibility level for the proposed LRWSS, including the possible Zalu Dam in the Xura River, and to define the most attractive composition and size of the water supply components, taking augmentation from groundwater resources into account.

This feasibility study provided for the assessment of all aspects that impact on the viability of utilising a combination of surface water (via the Zalu Dam on the Xura River) and groundwater (via boreholes) for the expansion of the existing water supply scheme to provide all water users in the study area with an appropriate level and assurance of water supply. The study is therefore required to:

- Identify all of the technical issues likely to affect implementation of the water supply scheme, and to define and evaluate all of the actions required to address these issues;
- Provide an estimate of cost with sufficient accuracy and reliability to ensure that management decisions related to water resourcing and supply in this study area can be made with confidence;
- Investigate irrigation viability; and
- Provide sufficient information to enable design and implementation to proceed without further technical investigation.

The required activities for this project have been grouped into 14 modules, as shown in the **Table 1.1**.

Table 1.1: Study structure

Modules	Deliverable
1. PROJECT MANAGEMENT 1.1 Study initiation and inception 1.2 Project management and administration	**Inception Report**
2. WATER RESOURCES	**Water Resources Report**
2.1 Hydrology	♦ Hydrology chapter
2.2 Yield analysis	♦ Yield Analysis chapter
2.3 Reservoir sedimentation	♦ Sedimentation chapter
3. GROUNDWATER AUGMENTATION	**Assessment of Augmentation from Groundwater Report**
4. RESERVE - ECOLOGICAL WATER REQUIREMENTS	**Reserve Determination Report** **Reserve Template**
5. WATER REQUIREMENTS	
5.1 Domestic water requirements	**Domestic Water Requirements Report**
5.2 Agriculture / Irrigation potential	**Irrigation Development Report**
6. WATER SERVICE INFRASTRUCTURE	**Water Distribution Infrastructure Report**
6.1 Distribution infrastructure	♦ Chapter in Water Distribution Infrastructure Report
6.2 Water quality	♦ Chapter in Water Distribution Infrastructure Report
7. PROPOSED ZALU DAM	
7.1 Site investigations	**Materials & Geotechnical Investigations Report**
7.2 Dam technical details	**Zalu Dam Feasibility Design Report**, including design criteria, dam type selection, dam sizing
8. COST ESTIMATE AND COMPARISON	♦ Included in relevant reports
9. REGIONAL ECONOMICS	**Regional Economics Report**
10. ENVIRONMENTAL SCREENING	**Environmental Screening Report** ♦ Scope of work for EIA
11. PUBLIC PARTICIPATION	♦ Included in Environmental Screening Report
12. LEGAL, INSTITUTIONAL AND FINANCIAL ARRANGEMENTS	**Legal, Institutional and Financial Arrangements Report**
13. RECORD OF IMPLEMENTATION OF DECISIONS	**Record of Implementation Decisions Report**
14. MAIN REPORT AND REVIEWS	**Main Study Report**

1.4 Scope of the Intermediate Preliminary Reserve Determination Study - Ecological Water Requirements (Module 4)

This report provides the Ecological Water Requirements (EWR, or the Ecological Reserve) for different ecological states at each EWR site for the Xura and Msikaba rivers, following the 8-step methodology for Reserve determinations.

This **Intermediate Reserve Determination Report** is the deliverable for **Module 4** of the *Feasibility Study for Augmentation of the Lusikisiki Regional Water Supply Scheme*. Module 4 of this study is being coordinated by Scherman Colloty & Associates.

1.4.1 Study Area and Location of EWR Sites

The locality of the EWR sites within the Management Resource Units (MRUs) as identified during this study is provided in **Tables 1.2** and **1.3** and in **Figure 1.2**. The process of delineation into MRUs is described in DWAF (2008a). This document also briefly describes delineation into EcoRegions Level I and II.

Table 1.2: Locality and characteristics of EWR sites

EWR site	River	Co-ordinates		EcoRegion (Level II)	Geozone1	Altitude (amsl)	MRU	Quat2	Gauge
		Latitude	Longitude						
EWR 1	Xura	-31.311441°	29.508271°	16.03	Lower Foothills	586	MRU 1: From source to T6H004 **(Figure 1.2a)**	T60F	T6H004
EWR 2	Msikaba	-31.251750°	29.74885°	17.01	Lower Foothills	208	MRU 2: Represented by T60G_06145 **(Figure 1.2b)**	T60G	none

1: Geomorphological zone

2: Quaternary catchment

Table 1.3: Detailed description and view of EWR sites

Site information	EWR sites	Illustration
EWR no and name River Previous EWR site National RHP[1] site (at present) Co-ordinates EcoRegion (Level II) Geozone Altitude (mams) Quaternary Farm name Hydrological gauge MRU	EWR 1: Xura Xura River n/a n/a -31.311441 S; 29.508271 E 16.03 Lower Foothills 586 masl T60F n/a T6H004 1	
EWR no and name River Previous EWR site National RHP site (at present) Co-ordinates EcoRegion (Level II) Geozone Altitude (m) Quaternary Farm name Hydrological gauge MRU	EWR 2: Msikaba Msikaba River n/a n/a -31.251750 S; 29.748850 E 17.01 Lower Foothills 208 masl T60G n/a none 2	

1: River Health Programme

The locality of EWR sites within the study area is illustrated in **Figure 1.2**. Note that different colours depict Level II EcoRegions.

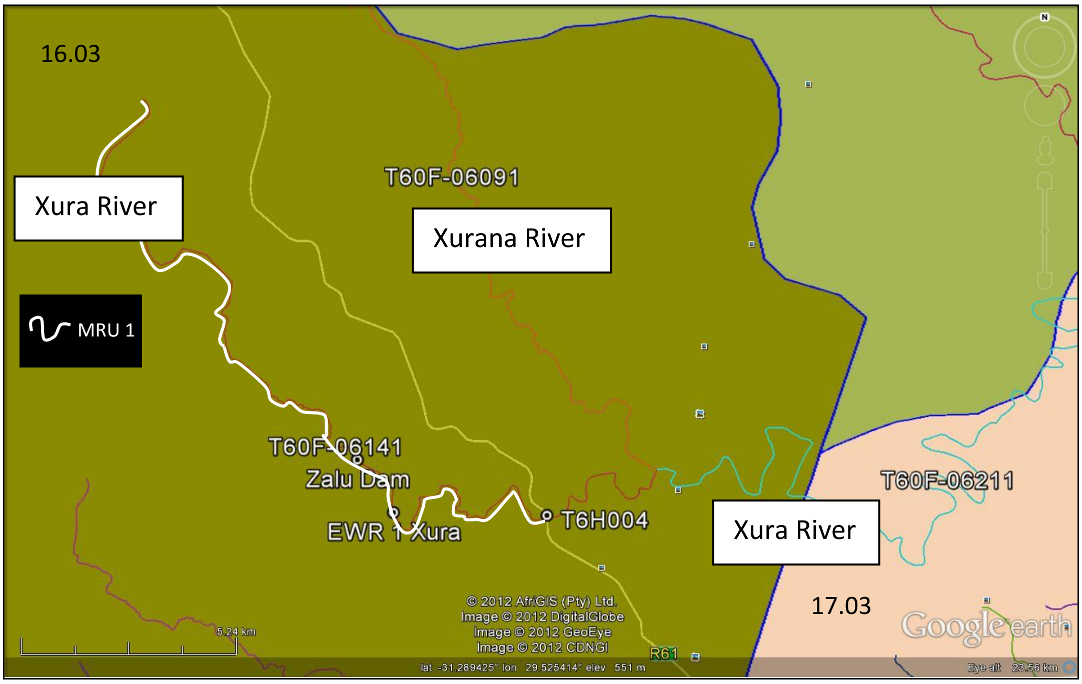

Figure 1.2 (a) **Locality of EWR 1 and MRU 1 in the Lusikisiki catchment**

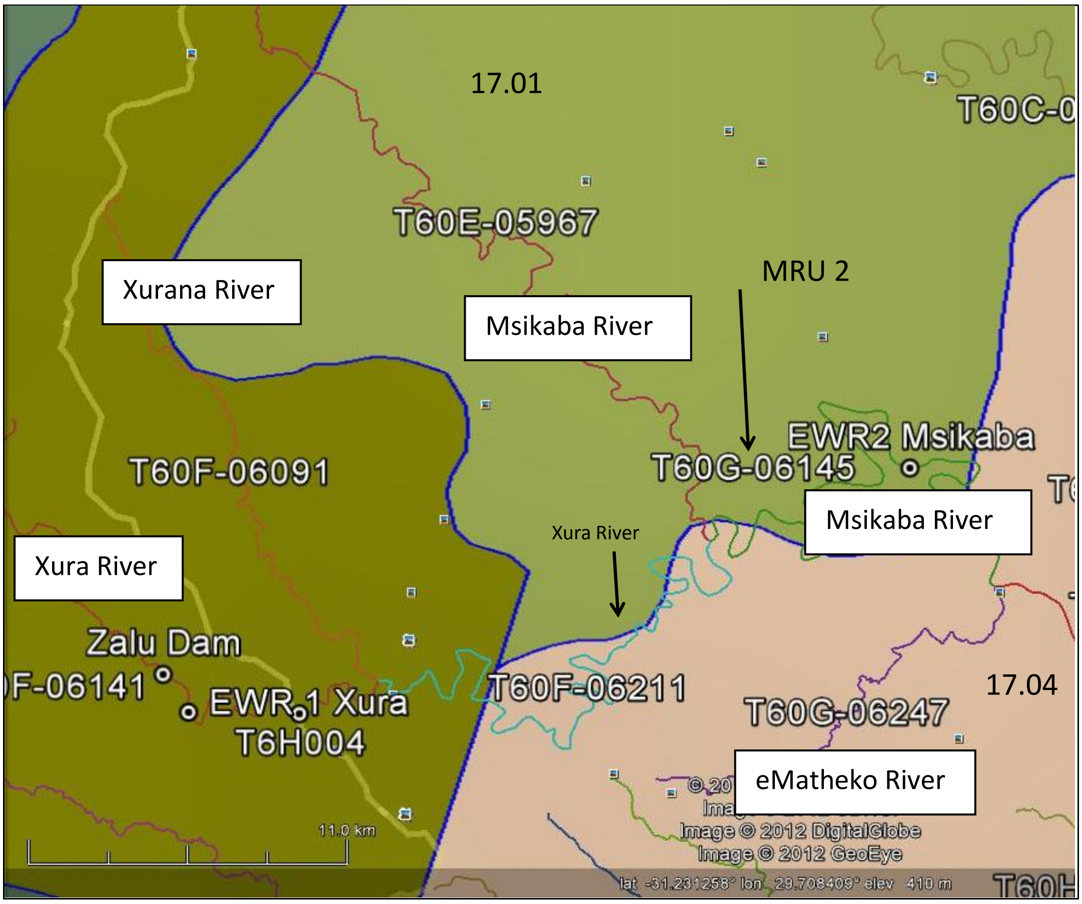

Figure 1.2 (b) **Locality of EWR sites and MRU 2 in the Lusikisiki catchment**

1.4.2 Objectives of the Intermediate Preliminary Reserve Study

The objectives of the study are to determine the EWR for different ecological states at each EWR site.

1.4.3 Data Availability

Information collated during physical surveys was used to provide the results in this report. The data availability is summarised in **Table 1.4**.

Table 1.4: Availability of data for each EWR site

Component	Data Availability	Conf[1]
EWR 1: Xura		
Hydrology	Daily observed flow downstream of EWR site – only 14 years of data at T6H004. Updated simulated monthly flow data (1920 – 2007) was available.	3
Diatoms	One sample collected from stone substrate at the EWR site. Good data was available on species present although no previous diatom data was available for the EWR site.	2.5
Water Quality	Confidence in the assessment was moderate to high. Although there were no metals, turbidity, temperature or dissolved oxygen (DO) data, no problems were anticipated around these parameters. A good data record existed for other parameters such as nutrients, salts, pH and some toxics.	3
Geomorphology (Geom)	Historical aerial photography was available from 1937, but these were of limited use due to the poor resolution and small size of the river in this upper catchment area. Google Earth imagery, maps and limited publications for the area were available. Site data were collected.	2
Fish	Previous survey data of the Xura River, undertaken by the fish specialist in 1999 and 2003 (Bok, unpublished data) was available. Sampling was undertaken on 13 Sep 2011 and 8 Feb 2012.	3
Macroinvertebrates (Inverts)	There were no known historic data for the river in this upper Resource Unit (RU). Data from numerous Eastern Cape (Transkei) rivers in nearby EcoRegions were reviewed for information. Sampling was undertaken on 13 Sep 2011 and 8 Feb 2012.	2.5
Riparian vegetation (Rip veg)	Little information existed for the study region with regard to detailed instream/riparian assessments, other than once off winter surveys conducted in the 1990s and Environmental Impact Assessment (EIA) studies related to vegetation assessments within the catchment. The specialist thus relied on past taxonomic surveys conducted during 1954, 1980 – 2004 and 2007 as well as surveys conducted prior to the study in 1999 and 2011. The collection data was accessed from the POSA (Plants of South Africa) Database (www.sanbi.org.za/posa).	3
EWR 2: Msikaba		
Hydrology	Updated simulated monthly flow was available at the EWR site. No flow gauges were present in the entire Msikaba River.	2
Diatoms	One sample collected from stone substrate at EWR site. Good data was available on species present although no previous diatom data was available for the EWR site.	2.5
Water Quality	Confidence in the assessment was low to moderate as results were extrapolated from EWR 1, and used together with land-use information.	2.5

Component	Data Availability	Conf[1]
Geom	Historical aerial photography was available from 1937 and recorded the morphological condition of the river from this time. Google Earth imagery, maps and limited publications for the area were available. Site data were collected.	3
Fish	Data were available from one previous survey of the EWR site in the upper Msikaba River undertaken by the specialist in 2006. No other data appeared available apart from current surveys undertaken on 14 Sep 2011 and 9 Feb 2012.	2
Invertebrates	The Msikaba River had been sampled approximately 40 km upstream of EWR 2 (just downstream of the road bridge and upstream of the confluence with the Xura River), in Ecoregion II 17.01, by DWA: EC. The locality was 31° 11′ 54.4″ S and 29° 36′ 29.2″ E. The sampling date was 4 Nov 2004. No other data for the system were found. Data from other sites in nearby catchments were reviewed for information. The Msikaba River at EWR 2 was sampled on 14 Sep 2011 and on 9 Feb 2012.	3
Riparian vegetation	Little information existed for the study region with regard to detailed instream/riparian assessments, other than once off winter surveys conducted in the 1990s and EIA related to vegetation assessments within the catchment. The specialist thus relied on past taxonomic surveys conducted by Acocks (1954), Dold (1980 – 2004), Hoare (2007) and own surveys conducted prior to the study in 1999 and 2011.	2

1: Confidence

1.4.4 This Report

The report consists of:

Chapter 1: Introduction: This chapter provides an overview of the feasibility study, the *Intermediate Preliminary Reserve Determination Study*, study area, objectives of the study and data availability.

Chapter 2: Approaches and Methods: This chapter outlines the methods followed during the Ecological Reserve process. Summarised methods are provided for the EcoClassification and EWR scenario determination.

Chapters 3 and 7: EcoClassification: The EcoClassification results are provided for each EWR site.

Chapters 4-5 and 8-9: Determination of Stress Indices and EWR Scenarios: The stress indices for all physical and biological components at each EWR site are provided. These chapters provide results of different EWR scenarios with respect to low and high flows for the respective EWR sites. Aspects covered in these chapters are component and integrated/stress curves, generating stress requirements, general approach to high flows and final results.

Chapter 6: Operational Scenarios: The impacts of the proposed operational scenarios are evaluated at EWR 1. Scenarios were not evaluated for EWR 2 due to the distance of this site from the proposed dams. Proposed scenarios are linked to dam size and management.

Chapters 10 and 11: Conclusions and Recommendations/Monitoring: The EcoClassification and EWR scenario results are summarised and recommendations are made. Monitoring requirements (i.e. EcoSpecs and Thresholds of Probable Concern (TPCs)) and recommendations are covered in Chapter 11.

Chapter 12: References

2 APPROACHES AND METHODS

As indicated in the Terms of Reference, Ecological Water Requirements (EWRs) were determined applying the Intermediate Ecological Reserve Methodology (IERM) (DWAF, 1999). Detailed information on methods can be found in *Chapter 2 of DWA* (2009a), as prepared for the *Outeniqua Reserve Determination Study*. The methodology consisted of two different steps:

- EcoClassification; and
- EWR quantification of different ecological states.

These two steps are discussed in the following sections.

2.1 ECOCLASSIFICATION

The EcoClassification process was followed according to the methods of Kleynhans and Louw (2007). Information provided in the following sections is a summary of the EcoClassification approach. For more detailed information on the approach and suite of EcoStatus methods and models, refer to:

- Physico-chemical Driver Assessment Index (PAI): Kleynhans *et al*. (2005); DWAF (2008b);
- Geomorphological Driver Assessment Index (GAI): Rowntree (2013);
- Fish Response Assessment Index (FRAI): Kleynhans (2007);
- Macroinvertebrate Response Assessment Index (MIRAI): Thirion (2007);
- Riparian Vegetation Response Assessment Index (VEGRAI): Kleynhans *et al*. (2007); and
- Index of Habitat Integrity (IHI): Kleynhans *et al*. (2009).

EcoClassification refers to the determination and categorisation of the Present Ecological State (PES) (health or integrity) of various biophysical attributes of rivers compared to the natural (or close to natural) reference condition. The purpose of EcoClassification is to gain insight into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the river. The EcoClassification process also supports a scenario-based approach where a range of ecological endpoints has to be considered and the consequential responses assessed. The latter is vital to evaluate ecological risk and to identify potential trade-offs (terms and conditions apply).

The state of the river is expressed in terms of biophysical components:

- Drivers (physico-chemical, geomorphology, hydrology), which provide a particular habitat template; and
- Biological responses (fish, riparian vegetation and macroinvertebrates).

Different processes are followed to assign a category (A→F; A = Natural, and F = Critically Modified) to each component. Ecological evaluation in terms of expected reference conditions, followed by integration of these components, represents the Ecological Status, or EcoStatus, of a river. The EcoStatus can therefore be defined as the totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support appropriate natural flora and fauna (modified from: Iversen *et al*., 2000). This ability relates directly to the capacity of the system to provide a variety of goods and services.

2.1.1 Process

The steps followed in the EcoClassification process are as follows:

- Determine the reference conditions for each component;
- Determine the Present Ecological State (PES) for each component, as well as for the integrated EcoStatus;
- Determine the trend for each component, as well as for the EcoStatus;
- Determine the reasons for the PES and whether these are flow or non-flow related;
- Determine the Ecological Importance and Sensitivity (EIS) for the biota and habitat;
- Considering the PES and the EIS, suggest a realistic Recommended Ecological Category (REC) for each component, as well as for the EcoStatus; and
- Determine alternative Ecological Categories (AECs) for each component, as well as for the EcoStatus.

Note: The Alternative Ecological Categories (AECs) are designed by using a combination of the most likely impacts or changes that could result in a decline or improvement of the present state. This could include both flow and non-flow related changes depending on the issues governing conditions at the site.

The flow diagram (Kleynhans and Louw, 2007) (**Figure 2.1**) illustrates the process.

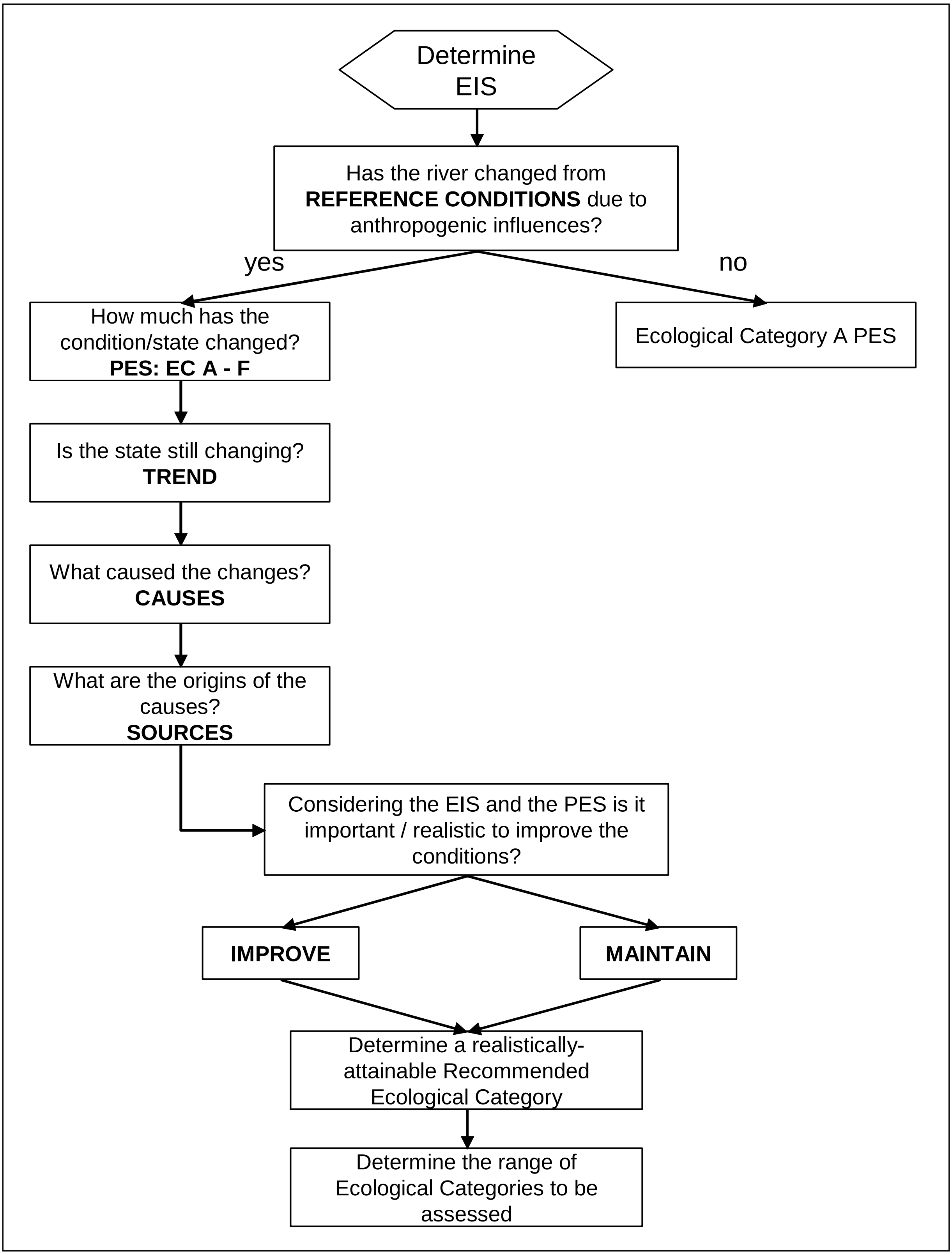

Figure 2.1: Flow diagram illustrating the information generated to determine the range of ECs for which the EWR will be determined

2.1.2 General Approach

The Level 4 EcoStatus assessment (Kleynhans and Louw, 2007) was applied according to standard methods. The minimum tools required for this assessment are shown in **Figure 2.2** (Kleynhans and Louw, 2007). Shaded blocks refer to factors influencing instream habitat integrity for the drivers and biotic instream integrity in terms of the biotic response indices.

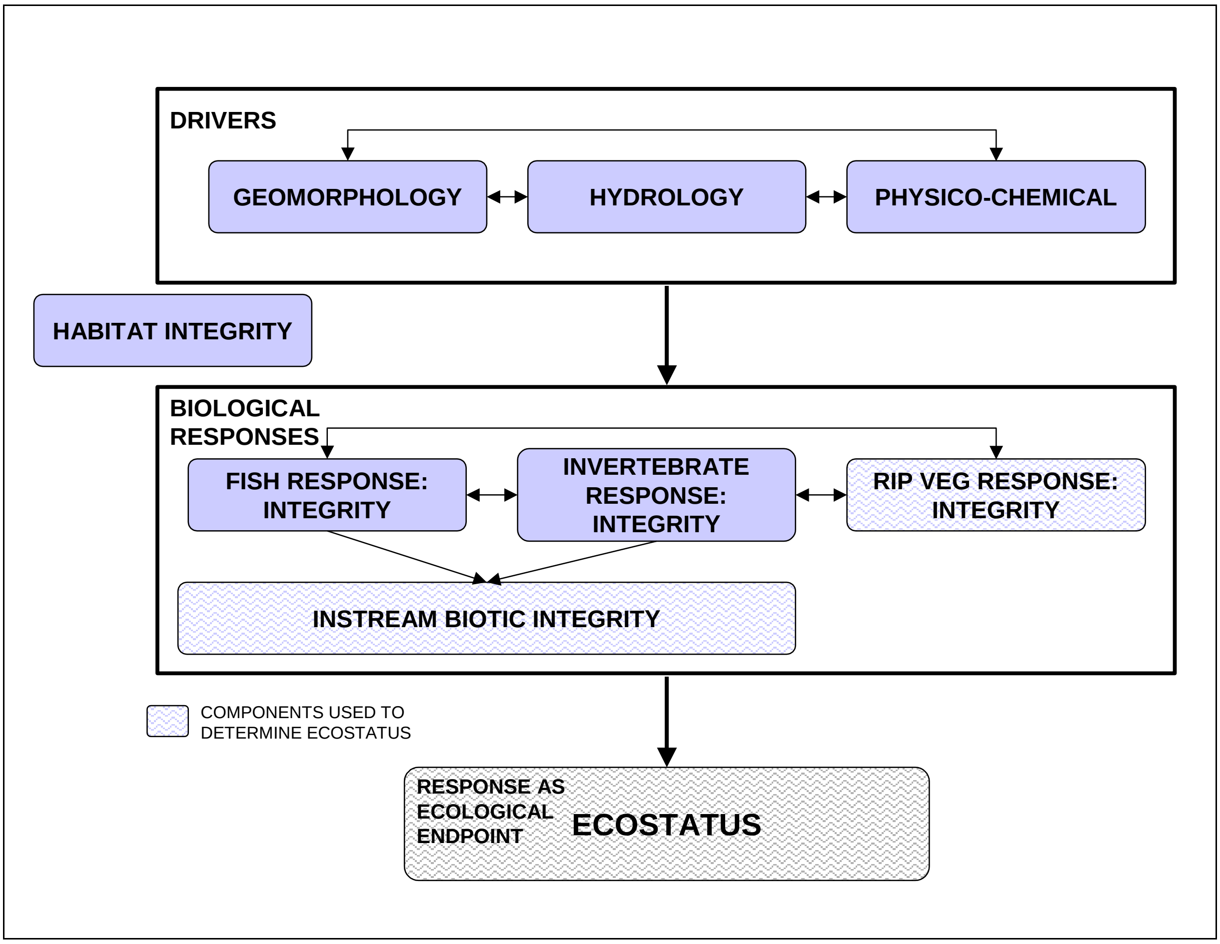

Figure 2.2: EcoStatus Level 4 determination

The role of the EcoClassification process is, amongst others, to define the various ECs for which Ecological Water Requirements (EWR) will be set. It is therefore an essential step in the EWR process. The EWR process is essentially a scenario-based approach and the EWR determined for a range of ECs are referred to as EWR scenarios. The range of ECs would include the PES, REC (if different from the PES) and the AECs. When designing a scenario that could decrease the PES, flow changes are first to be evaluated. If this, and the response of other drivers, is deemed to be insufficient on its own to change the category, then the current non-flow related impacts are 'increased', or new non-flow related impacts are included. It is attempted to create a realistic scenario; however, it must be acknowledged that there are many scenarios that could result in a change from the PES. Best attainable state for future management is important to work towards realistic, practicable implementation, but in a sustainable manner without compromising the ecological baseline.

2.1.3 Ecological Importance and Sensitivity (EIS)

The EIS model, developed by Dr CJ Kleynhans of D: Resource Quality Studies (D: RQS) of DWA (DWAF, 1999), was used for this study. This approach estimates and classifies the EIS of the streams in a catchment by considering a number of components surmised to be indicative of these characteristics. Note that the results from the updated PES/EI/ES study of 2013 were not available at the initiation of the LRWSS study.

The following ecological aspects are considered as the basis for the estimation of EIS:

- The presence of rare and endangered species, unique species (i.e. endemic or isolated populations) and communities, intolerant species and species diversity were taken into account for both the instream and riparian components of the river; and
- Habitat diversity was also considered. This includes specific habitat types such as reaches with a high diversity of habitat types, i.e. pools, riffles, runs, rapids, waterfalls, riparian forests, etc.

With reference to the points above, biodiversity in its general form (Noss, 1990) is taken into account as far as the following available information allowed:

- The importance of a particular river or stretch of river in providing connectivity between different sections of the river, i.e. whether it provided a migration route or corridor for species, was considered;
- The presence of conservation or relatively natural areas along the river section also served as an indication of ecological importance and sensitivity; and
- The sensitivity (or fragility) of the system and its resilience (i.e. the ability to recover following disturbance) of the system to environmental changes was also considered. Consideration of both the biotic and abiotic components was included here.

The EIS results of the study are summarised in this report and the models are provided electronically on a CD supplementary to this document. EIS categories are summarised in **Table 2.1.**

Table 2.1: EIS categories (DWAF, 1999; Kleynhans and Louw, 2007)

EIS Categories	General Description
Very high	Quaternaries/delineations that are considered to be unique on a national or even international level based on unique biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) are usually very sensitive to flow modifications and have no or only a small capacity for use.
High	Quaternaries/delineations that are considered to be unique on a national scale due to biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) may be sensitive to flow modifications but in some cases, may have a substantial capacity for use.
Moderate	Quaternaries/delineations that are considered to be unique on a provincial or local scale due to biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) are usually not very sensitive to flow modifications and often have a substantial capacity for use.
Low/Marginal	Quaternaries/delineations which are not unique at any scale. These rivers (in terms of biota and habitat) are generally not very sensitive to flow modifications and usually have a substantial capacity for use.

2.2 EWR DETERMINATION

The Habitat Flow Stressor Response method (HFSR) (IWR S2S, 2004; O'Keeffe et al., 2002), a modification of the Building Block Methodology (BBM) (King and Louw, 1998), was used to determine the low (base) flow EWR. This method is one of the methods used to determine EWRs at the intermediate level.

The basic approach is to compile stress indices for fish and macroinvertebrates. The stress index describes the consequences of flow reduction on flow-dependent biota (or guilds[1]) and is determined by assessing the response of the critical habitat, and hence the indicator guild, to a flow reduction. The stress index therefore describes the habitat conditions and biota response for fish and macroinvertebrates at a range of low flows. The fish and macroinvertebrate stress-flow relationship may not be the same since the responses to the same flow will/can result in different stress for fish and macroinvertebrates, as well as for different seasons (wet and dry).

A stress flow index is generated for every component (fish and macroinvertebrates) and season (wet and dry), and describes the progressive response of flow-dependent biota to flow reduction. The stress flow index is generated in terms of habitat and hence biotic response.

[1] *Guild: a group of species that exploits the same kind of environmental resources in a similar way*

The stress index is described as an instantaneous response of habitat to flow in terms of a 0 to 10 index relevant for the specific site where:

- 0: Optimum habitat with the least amount of stress possible for the indicator groups (fixed at the natural maximum baseflow which is based on the 10% annual value using natural separated baseflows).
- 10: Zero discharge (note: surface water may still be present) or maximum stress on indicator group.
- 2 to 9: Gradual decrease in habitat suitability and an increase in stress as a result of decreased discharge.

The ecohydraulics for the site are mainly used to evaluate the range of flows (from zero flow to maximum separated baseflow). This is accomplished through the use of the MS Excel-based Fish Flow Habitat Assessment (FFHA). This model was developed by Dr N. Kleynhans, D: RQS, DWA during 2008 and applied to a number of studies, for example, the *Upper Vaal Comprehensive Reserve Study* (DWA, 2009b). The optimal critical habitats for each indicator species/taxon or guild are identified by the relevant specialist. An automated habitat suitability and stress value is then calculated for each flow (discharge) evaluated, based on the extent of change of these critical habitats from the natural flow. The automated stress values are then checked and refined through the approach described below.

The instantaneous response of fish and macroinvertebrate breeding habitat, abundance, cover, connectivity, and water quality are derived by considering (amongst others) rated velocity depth classes (in terms of abundance) to flow changes based on a 0 to 5 scale where:

- 0 = Velocity - depth class is absent under the specific flow condition/No habitat available;
- 1 = Velocity - depth class is rare under the specific flow condition/Very low occurrence of habitat;
- 2 = Velocity - depth class is sparse under the specific flow condition/Low occurrence of habitat;
- 3 = Velocity - depth class occurs moderately under the specific flow condition/ Moderate occurrence of habitat;
- 4 = Velocity - depth class occurs abundantly under the specific flow condition/Large/ Good occurrence of habitat; and
- 5 = Velocity - depth class is very abundant under the specific flow condition/ Optimum occurrence of habitat.

The integrated stress curve represents the highest stress for either fish or macroinvertebrates at a specific flow for the wet and dry season.

The fish and macroinvertebrate stress indices are then used to convert both the natural and present day flow time series to a stress time series. The stress time series is subsequently converted to a stress duration graph for the highest and lowest flow months. This provides the specialist with information on how much the stress has changed from the natural state under present conditions due to changes in the flow regime, i.e. if flow has decreased from the natural state, stress would increase, and vice versa. This is an iterative process and if specialists do not agree with the levels of stress under natural conditions based on their knowledge of the species, the stress indices are refined.

Tools used to determine the stress indices require specialist knowledge and information about the indicator species habitat requirements, the hydraulics in a specific format and the natural hydrology.

At this stage only the instantaneous response of habitat and biota to flow reduction has been assessed. This means that the actual stress requirements ***at specific durations and during specific seasons*** to maintain the biota in a certain ecological state, has not yet been assessed. The information used to determine the Ecological Category for the instream biota is considered when determining the stress required to maintain or achieve this ecological state. The stress requirement is set for drought and maintenance conditions. Drought stress is set at 5% exceedence. The maintenance stress is set at a percentage which is determined based on the low flow hydrological variability of the specific river being assessed. The more variable the river, the higher the percentage at which maintenance stress is set. Any stress requirements for other percentage points can also be provided.

The requirements are still provided in terms of the separate fish and macroinvertebrate indices. Obviously one can only deal with one stress-flow relationship, and an integrated stress index is therefore compiled. The integrated stress curve comprises the highest stress of either the fish or macroinvertebrate component at each specified flow. This forms the integrated stress curve and the results for fish and macroinvertebrates must therefore be converted to integrated stress in order to be comparable.

Figure 2.3 illustrates an example of the interpolated individual component stresses as well as the integrated curve. The black curve represents the integrated curve, while the other lines represent the stress flow relationships for the various components. The integrated curve (black curve) in this case consists of the flow dependent macroinvertebrates (FDI: flow dependent invertebrates) (red curve) for the stress range 3 to 10, and fish (LSR: large semi reophilics) for the stress range 0 to 3.

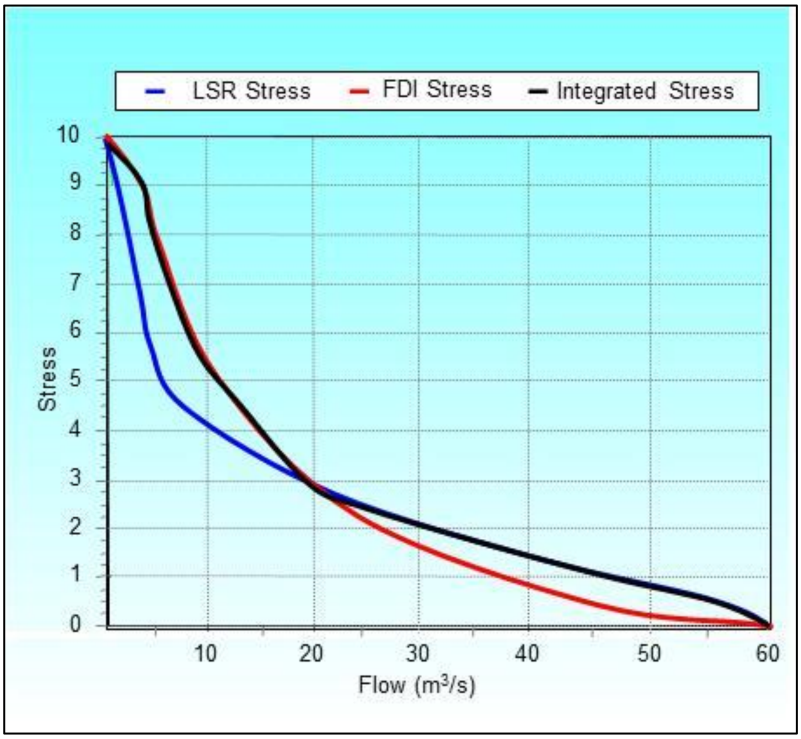

Figure 2.3: Component and integrated stress curves

Specialists determine the allowable stress (based on the habitat and biota response) for a range of durations and for different ecological categories. The complexity here, as with all flow requirement methods, is to interpret an instantaneous response in terms of duration and seasonal requirements. The required stress is therefore converted to integrated stress and plotted on a graph, which also shows the natural and present day flow converted to integrated stress. This therefore supplies the 'hydrological check' to ensure that the requirements are realistic in terms of the natural hydrology and present day hydrology (only used when realistic and of reasonable confidence). The low flow stress requirement for an EC consists of the component requirement with the lowest stress requirement (highest flow requirements). For example, if fish have a requirement at 5% duration of a stress of 5 to achieve a C Ecological Category, and macroinvertebrates have a requirement for a C category of 8, the final requirement will be a stress of 5 as the 5 stress would cater for the macroinvertebrates, whereas the 8 stress could not cater for the fish and would result in the fish being in a lower EC. These final requirements are therefore connected manually (a 'hand drawn line' as the required stress duration) and illustrated as a stress duration graph.

Figure 2.4 is an example of a stress duration graph and illustrates the stress requirements and stress points required for a D PES and REC (green arrowed curve), and C AEC (purple arrowed curve). Present Day (red line) and Reference or Natural (blue line) flows are also shown. The different coloured circles indicate the requirements of the instream biota for the specific EC. Each circle is labelled as follows and indicates a different biotic component:

- LSR – large semi-rheophilic fish guild;
- FDI – flow dependent (macro)invertebrates; and
- MVI – marginal vegetation (macro) invertebrates.

In this example the drought flows (5%) of the different biotic components are the same for all ECs.

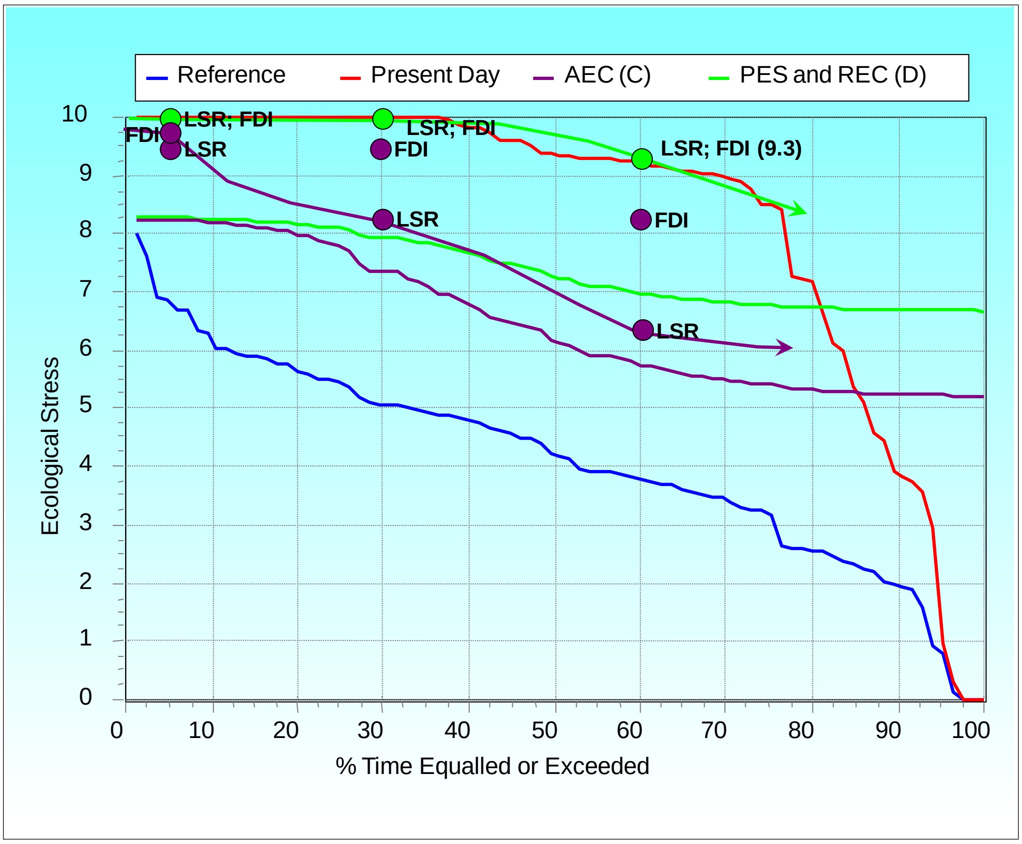

Figure 2.4: Stress duration curve for a D PES and REC, and C AEC up - DRY SEASON

These stress requirements (provided for ***two key months of the high and low flow season***), must now be manipulated to provide a complete low flow regime as follows:

- The desktop ECs being assessed, as well as the natural and present day flows, are converted to stress and plotted (see **Figure 2.4**). The hydrologist then modifies the desktop stress curve to fit the specialist stress requirements using the Desktop Reserve Model (DRM) and the Flow Stressor Response model within SPATSIM (Spatial and Time Series Modelling) (Hughes and Forsythe, 2006)[2]. The process is specifically designed this way as the seasonal characteristics of the hydrology and the rules for the different ECs are built into the desktop estimate[3]. This would therefore ensure that the requirements set by specialists do not deviate significantly from the natural seasonal variability;
- The hydrologist can use a range of options to achieve the requested modifications to the DRM curves, such as changing the annual EWR volume, changing specific monthly volumes, changing durations of either drought or maintenance flows, changing the seasonal distribution and changing the category rules and shape factors;
- The DRM will then be used to extrapolate the requirements to the remainder of the months or seasons and specialists can check these months for correctness; and
- All changes made to the DRM to fit the specialist requirements, together with the graphs for the final low flow stress requirements, are documented.

2.2.1 High Flows

The approach to set the high flow EWR is a combination of the Downstream Response to Imposed Flow Transformation (DRIFT) (Brown and King, 2001) approach and the BBM (King and Louw, 1998). The high flows are determined as follows:

- Flood ranges for each flood class and the geomorphology and riparian vegetation functions are identified and tabulated by the relevant specialists. These are provided to the instream specialists who indicate:
  - which instream function these floods cater for;
  - whether additional instream functions apart are required; and
  - whether they require any additional flood classes to the ones identified.
- The number of floods for each flood class is identified as well as where (early, mid, late) in the season they should occur;

[2] *SPATSIM is an integrated data management and modelling software package developed in Delphi using the spatial data handling functions of Map Objects. It has been designed to allow the efficient management, processing and modelling of the type of data associated with a range of water resource assessment approaches used in South Africa including stream flow and other time series data display and analysis, rainfall-runoff models (including the Pitman monthly model) and a variety of Ecological Reserve determination models.*

[3] *The desktop estimates for specific ECs include rules for these ECs based on long-term data records and expert information.*

- These numbers of floods are then adjusted for the different Ecological Categories;
- The floods are evaluated by the hydrologist to determine whether they are realistic. A nearby gauge with daily data is used for this assessment. Without this information it is difficult to judge whether floods are realistic;
- If daily data is available close to the EWR site, the hydrologist analyses the flow record to establish the maximum flood, typical floods with certain recurrence intervals (1:1 year, 1:5 year, etc.), the peak flow as well as the length (number of days) of specific floods and documents the months in which the floods are expected to occur. This serves to ensure that the specialist's requests for floods are realistic (and in line with the natural hydrograph); and
- The floods are then included in the DRM to provide the final *.rul* and *.tab* files (see paragraph 2.2.2). The latter provides critical information for the computation of the final legal Reserve templates.

2.2.2 Final Flow Requirements

The low and high flows are combined to produce the final flow requirements for the REC as:

- An EWR table (**.tab*), which shows the EWR for high flows and low flows for each month separately. Floods with a frequency higher than 1:1 are often not included when compiling the EWR, as they cannot be managed. The water resources models used for system and yield analyses is static with regard to water allocation and have no memory to determine whether these floods were released during a previous month. Visual checks for compliance with flood releases are recommended; and

- An EWR rule table (**.rul*) which provides the recommended EWR flows as a duration table, showing flows which should be provided when linked to a natural trigger (natural modelled hydrology in this case). EWR rules are supplied for both total flows as well as for low flows only.

The rule curve is useful for water resources modelling and as an input to the operating rules for implementing Reserve flows, whilst the EWR table provides information on the MAR at the EWR as well as the EWR required, category and rule curve definition. The information on the EWR is broken down to show the split between high and low maintenance flows, and also provides drought flows.

3 ECOCLASSIFICATION: EWR 1 (XURA RIVER)

3.1 EIS RESULTS

The EIS evaluation resulted in a **MODERATE** importance rating. The highest scoring metrics were:

- Unique (instream) species: *Barbus sp*. is still being described and possibly only occurs in four rivers;
- Diversity of habitat types and features (instream habitat): Riffles, shoots, rapids, marginal vegetation, pools, back waters and undercut banks;
- Refugia and critical habitat (instream habitat): Important due to lack of strongly perennial tributaries;
- Diversity of habitat types and features (riparian habitat): Wetlands and off-channel pools upstream of site; and
- Migration corridor (riparian): Very distinct and different type of habitat in valley within grassland areas. Important for birds, and other riparian fauna.

3.2 REFERENCE CONDITIONS

The reference conditions (RC) at EWR 1 are summarised in **Table 3.1**.

Table 3.1: EWR 1: Reference conditions

Component	Reference conditions	Conf
Hydrology	14.16 million m³. Updated simulated natural flow data (1920 – 2007).	4
Water Quality	No Reference Condition (RC) data. RC based on A river benchmark conditions as outlined in DWAF (2008b).	2
Geomorphology	The river channel would have been a small, single channel characterised by bedrock and fixed boulder bed with fines in the lee areas and well vegetated marginal and riparian zone. An alluvial small river with weakly developed paired terraces would have been present. The banks would be alluvial (silt) and the bed composed of cobbles and boulders and gravels.	3
Riparian vegetation	It was well understood that broad riparian zones would not be a feature of the study area due to the steep incised valleys, and when found these would be associated with scarp forest or thickets that extend down into these river valleys, while the remainder of the catchments would be dominated by grassland and emergent vegetation within the riparian zones. The inferred reference state was thus based on the present structure and function of the observed present day species (cover), while it was understood that species abundance had been altered drastically and a high number of species observed in the 1940's were no longer observed in the greater catchments, and are only found in small populations in isolated areas downstream of the proposed development. Confidences were mostly moderate, limited by the lack of information that existed on the reference state of these systems (50 – 100 years ago).	2
Fish	Three fish species expected to be present (*Barbus amatolicus*, *Anguilla mossambica* and *A. marmorata*). Clean, unbedded rocks in pools as well as in riffles, deep refuge pools with little silt on substrate.	3
Inverts	Of the nearby Eastern Cape river sites reviewed, only one site, with a single sample, was considered appropriate as a reference site, in terms of similar channel size, position in catchment, habitat availability, invertebrate community and overall SASS5 (South African Scoring System version 5) score: **Ntafufu River**, locality: S 31° 29' 50.6", E 29 °31 43.2". The SASS5 score was slightly better than at EWR 1. The data was sourced from DWA: EC. The sample date for the data was 4 Nov 2004. In the natural (reference) state, one would have expected better water quality (clearer water with low nutrient levels and lower turbidity). Surfaces of cobbles and boulders would be clear of substrates and algae. There may have been more indigenous leaf-fall (low impact).	2.5

3.3 Present Ecological State

The Present Ecological State (PES) reflects the changes in terms of the Ecological Category (EC) from reference conditions. The summarised PES information is provided in **Table 3.2** and **Table 3.3** provides summarised water quality data.

Table 3.2: EWR 1: Present Ecological State

Component	PES description	EC	Conf
Hydrology	The EWR site was upstream of the abstraction point of the Lusikisiki Water Treatment Works (WTW) at gauge T6H004. Negligible changes in flow occurred at the site with some forestry and probably local abstractions and cattle watering present.	A/B	4
Water Quality	PES data from gauging weir T6H004; 1995-2011; n = over 100 for all sampled parameters was available. The main water quality issue was some nutrient enrichment due to catchment-based activities.	A/B	4
Geomorphology	The river channel was a small, single channel with a bedrock and fixed boulder bed, with fines in the lee areas. The riparian zone was generally well-vegetated although trampling and grazing has reduced vegetation cover and increased erosion in some places. The low cut banks evident during the site visit were natural, being caused by the recent large floods.	A/B	4
Riparian vegetation	The present marginal zone was close to the reference state, possibly with a small loss of species cover and abundance due to trampling, grazing and alien plant cover. As a result only ten dominant marginal species were observed. These were however typical of the region, with no rare or endemic species being observed. The species that were found have adaptive life histories, able to tolerate low to no flow conditions for short periods as well as high flow conditions. Most species require moist soils in order to survive. Lower and Upper zone species were largely flow independent and only require inundation for very short periods at least once a year. The present cover and abundance was however limited by a small percentage of alien plant cover and a high degree of trampling and grazing.	B/C	3
Fish	All three expected species were found in abundance at the site and good quality habitat was present with all expected hydraulic habitats suitable for fish. Limited siltation in deep pools was evident as well as algal growth on rocks indicating nutrient input, but this had a limited impact on fish.	A/B	4
Inverts	The invertebrate community reflected the impacts to this section of the river, in that it included a number of sensitive, flow-dependent taxa scoring >10 (Perlidae, Baetidae >2 spp, Heptageniidae, Psephenidae, and Athericidae). The change from the natural state, in which one would anticipate additional taxa of this sensitivity level (e.g. Philopotamidae, Platycnemidae, and Pisuliidae) probably related largely to the increase in nutrient levels (algae on upper and front surfaces of rocks decrease habitat availability) and increased turbidity at the site.	A/B	3

Table 3.3: EWR 1: Present Ecological State: Water Quality

RIVER	Xura River	Water Quality Monitoring Points	
EWR SITE	1	**RC**	Benchmark conditions for an A category river (DWAF, 2008b)
		PES	T6H004; 1995-2011; n = over 100 for all sampled parameters.
Confidence assessment	Confidence in the assessment was **moderate to high**. Although there were no metals, turbidity, temperature or DO data, no problems were anticipated around these parameters. A good data record existed for other parameters.		
Water Quality Constituents		**Value**	**Category (Rating input to the PAI model) / Comment**
Inorganic salts (mg/L)	$MgSO_4$	-	The Tool for Ecological Aquatic Chemical Habitat Assessment (TEACHA) was not used for organic salts as these were not triggered by high Electrical Conductivity values or anticipated issues in the catchment.
	Na_2SO_4	-	
	$MgCl_2$	-	
	$CaCl_2$	-	
	NaCl	-	
	$CaSO_4$	-	
Nutrients	SRP	0.021	C (2)

RIVER	Xura River	Water Quality Monitoring Points	
(mg/L)	TIN	0.978	C (2)
Physical variables	pH (5^{th}+95^{th} percentiles)	7.45 + 8.33	A/B (0.5)
	Temperature	-	Site was not located downstream of a dam, so temperature and oxygen fluctuations were not expected. Bedrock prominent and small stream, so possibly some temperature fluctuation would be expected. Temperature: A/B (0.5); DO: A (0)
	Dissolved oxygen (DO)	-	
	Turbidity (NTU)	-	No significant sedimentation observed.
	Electrical conductivity (mS/m)	31.58	A/B (0.5)
Response variable	Biotic community composition: MIRAI score	89	A/B
	Fish: FRAI score	88.8	A/B
	Diatoms	SPI*=15.4	B (1) (n = 1)
Toxics	Ammonia	0.006	A (0)
	Fluoride	0.214	A (0)
OVERALL SITE CLASSIFICATION (based on PAI model)		**A/B (89.6%)**	

**SPI: Specific Pollution sensitivity Index*

3.3.1 EWR 1: Trend

The trend was also assessed. Trend refers to the situation where the abiotic and biotic responses have not yet stabilised in reaction to catchment changes. The evaluation was therefore based on the existing catchment condition. The trend for all components was stable (refer to Table 3.7) as there had been so little change from reference conditions. There were thus limited developments in recent years to which the biological responses still had to react to.

3.3.2 EWR 1: PES Causes and Sources

The reasons for changes from the reference conditions had to be identified and understood. These are referred to as causes and sources. The PES for the components at EWR 1 as well as the causes and sources for the PES are summarised in **Table 3.4**.

Table 3.4: EWR 1: PES Causes and sources

	PES	Conf	Causes	Sources	F[1]/NF[2]	Conf
Hydro[3]	A/B	4	Decrease in low flow.	Forestry. Cattle watering, alien vegetation (negligible).	F	3
Water Quality	A/B	4	Nutrient levels were elevated, with benthic algae evident on rocks. No toxics were expected in the system.	Elevated nutrient levels were linked primarily to land-use, e.g. settlements, overflowing school latrines and instream washing.	NF	3
Geom	A/B	4	Slight trampling at site, and slight increase in erosion in catchment from cattle.	Cattle (livestock).	NF	4
Riparian vegetation	B/C	2.9	Reduced plant cover due to trampling.	Cattle, goats and limited pedestrian access.	NF	4
			Reduction in plant cover and abundance.	Alien plant growth.		
			Reduction in plant cover due to erosion (very limited).	Trampling and uprooting of alien plant growth during high flows in the upper zone.		
Fish	A/B	3	Some siltation in deep pools.	Bank collapse due to cattle trampling and farming activities which included overgrazing and fields near the river.	NF	2
			Algal growth on rocks and filamentous algae in backwaters.	Nutrients from domestic effluent and nearby school, cattle droppings.		
			Migration of eels partially blocked.	Gauging weir at end of Resource Unit (RU), a partial barrier particularly during low flows.		
Inverts	A/B	3	Low levels of disturbance.	Cattle trampling, footpaths.	NF	2.5
			Increased turbidity.	Slight erosion in the catchment.		
			Increased nutrient levels.	Cattle and human waste, clothes washing.		
			Alien vegetation.	Disturbance due to trampling and foot-traffic.		

1: Flow related
2: Non Flow related
3: Hydrology

The major issues that have caused the change from reference conditions were non-flow related (catchment) activities which included:

- Trampling and limited erosion (cattle);
- Increased nutrient levels (cattle, human waste, clothes washing); and
- Alien vegetation.

3.3.3 EWR 1: PES EcoStatus

To determine the EcoStatus, the macroinvertebrates and fish component scores firstly had to be combined to determine an instream EC. The instream and riparian ECs were then integrated to determine the EcoStatus. Confidence was used to determine the weight which the EC should carry when integrated into an EcoStatus (riparian, instream and overall). The EC percentages are provided (**Table 3.5**) as well as the portion of those percentages used in calculating the EcoStatus.

Table 3.5: EWR 1: EcoStatus

INSTREAM BIOTA	Importance Score	Weight
FISH		
1. What is the natural diversity of **fish** species with different flow requirements?	2	80
2. What is the natural diversity of **fish** species with a preference for different cover types?	4	100
3. What is the natural diversity of **fish** species with a preference for different flow depth classes?	3	90
4. What is the natural diversity of **fish** species with various tolerances to modified water quality?	2	80
MACROINVERTEBRATES		
1. What is the natural diversity of **invertebrate** biotopes?	2	90
2. What is the natural diversity of **invertebrate** taxa with different velocity requirements?	3	100
3. What is the natural diversity of **invertebrate** taxa with different tolerances to modified water quality?	2	90
Fish	**88.8 (A/B)**	
Macroinvertebrates	**89.9 (A/B)**	
Confidence rating for instream biological information	**3**	
INSTREAM ECOLOGICAL CATEOGORY	**A/B**	
Riparian vegetation	**78.8 (B/C)**	
Confidence rating for riparian vegetation zone information	**3**	
ECOSTATUS	**B**	

3.4 RECOMMENDED ECOLOGICAL CATEGORY

The REC was determined based on ecological criteria only and considered the EIS, the restoration potential and the attainability thereof. As the EIS was **MODERATE,** and the PES (instream) was already in a good state, no improvement was required. One might have argued that the riparian vegetation of a B/C EC should have been improved to a B EC; however, this improvement was based on non-flow related aspects. The REC was therefore set to maintain the instream PES of an A/B category.

3.5 ALTERNATIVE ECOLOGICAL CATEGORY (AEC↓):

The hypothetical scenario focused on the presence of Zalu Dam assuming no knowledge of the operation and design and that no releases for EWRs were to be made. Assumed responses to the hypothetical scenario included:

- Hydrology: Decreased baseflows and decreased floods;

- Geomorphology: Loss of floods would result in pools willing up with sediment and cutting of marginal zones;
- Water Quality: Increased nutrients resulting in increases in temperature and oxygen;
- Riparian vegetation: Increased alien vegetation due to lack of floods. More shading would occur due to increased vegetation;
- Fish: Decreased Frequency of Occurrence (FROC) and connectivity; and
- Macroinvertebrates: Decreased abundance of rheophilic taxa. Loss of vegetation would affect the juveniles.

Each component was adjusted to indicate which metrics would react to the hypothetical scenario. The rule based models are available electronically and summarised in **Table 3.6**.

Table 3.6: EWR 1: AEC↓

	PES	AEC↓	Comments	Conf
Water Quality	A/B	B/C	Reduction in baseflows and floods would result in a number of water quality changes, i.e. increase in nutrient levels, an anticipated small increase in salts and turbidity, and possible decreases in oxygen levels. Increasing sedimentation would result in a shallower system, with associated temperature increases.	3
Geom	A/B	High C	It was assumed that there would be at least some impact on flows and sediment delivery. This would increase sedimentation of pools and likely to cause erosion of the marginal zones (due to releases of sediment-free water).	2
Rip veg	B/C	C	Due to the possible reduction in floods, the present day alien vegetation could increase (cover) and out-compete the marginal vegetation. This would also reduce the overall marginal and instream vegetation, while increasing bank instability and would increase the potential for bank incision. Trampling and grazing would continue in the lower and upper zones, until a point where the alien vegetation completely encroached this zone, which would further reduce the cover and abundance of indigenous species.	2
Fish	A/B	B/C	Reduction in fish and eel numbers and FROC of eels would occur due to the loss of cover in the form of overhanging vegetation, undercut banks and root wads as well as rock structure cover in pools. Increased stress would occur due to reduced water quality - higher temperatures and lowered DO levels.	2
Inverts	A/B	B/C	A loss of smaller floods (and consequent loss of regular 'freshening'/resetting of instream habitat), the widening of the channel through scour (water downstream of the dam would be sediment poor), and the subsequent overall reduction in flow depth would occur. The increased shading from alien vegetation may shift the community balance in favour of shredders (Hydropsychidae and other caddisflies). The response of the invertebrate community to these changes would largely be a reduction in numbers and species of water-quality sensitive rheophilic taxa (Perlidae, Baetidae – loss of species, Heptageniidae, Tricorythidae, Athericidae, Psephenidae etc.).	2.5

3.6 Summary of EcoClassification Results

Table 3.7: EWR 1: Summary of EcoClassification results

Driver Components	PES & REC	Trend	AEC ↓
IHI HYDROLOGY	A/B		
WATER QUALITY	A/B		B/C
GEOMORPHOLOGY	A/B		C
Response Components	**PES**	**Trend**	**AEC↑**
FISH	A/B	0	B/C
MACRO INVERTEBRATES	A/B	0	B/C
INSTREAM	A/B	0	B/C
RIPARIAN VEGETATION	B/C	0	C
ECOSTATUS	B		C
INSTREAM IHI	A/B		
RIPARIAN IHI	B		
EIS	MODERATE		

4 EWR 1 (XURA RIVER): DETERMINATION OF STRESS INDICES

4.1 INDICATOR SPECIES OR GROUP

4.1.1 Fish Indicator Group: Small Semi-Rheophilic Species

As a result of the absence of any true rheophilic fish species in this system, two semi-rheophilic species were used. These were:

- The small semi-rheophilic species *Barbus anoplus* (BANO) (type n. sp. Transkei) was selected as indicator group for setting flows. This group generally requires Slow-Shallow (SS) and Slow-Deep (SD) flow-depth categories with inundated overhanging vegetation and marginal vegetation for spawning, usually available at higher flows. After egg hatching, larval development takes place in shallow sheltered, vegetated backwaters as optimal habitats. Juvenile and adult specimens have a high preference for SS habitats, with overhanging vegetation and shallow pools with un-embedded substrate as cover. Minimal flows are required to allow migration between reaches, with depths of about 10 - 15 cm adequate during the wet season; and
- The anguillid species, particularly juvenile and sub-adult *Anguilla mossambica*, prefer Fast-Shallow (FS) and Fast-Deep (FD) habitat among un-embedded cobbles and boulders in riffles. Sufficient depths >15 cm in critical riffle habitats are required for migration and dispersal of eels upstream from the lower reaches, particularly during the summer wet season.

4.1.2 Macroinvertebrate Indicator Group: Perlidae

Perlid stoneflies have a high preference for very fast flows (>0.6 m/s) with cobble substrates, and good water quality.

4.2 STRESS FLOW INDEX

A stress flow index was generated for every component (fish and macroinvertebrates) and season (wet and dry), and describes the progressive response of flow dependent biota to flow reduction. The stress flow index was generated in terms of habitat and hence biotic response. The integrated stress curve represents the highest stress for either fish or macroinvertebrates at a specific flow for the wet and dry season. The species stress discharges in **Table 4.1** and **4.2** indicate the discharge evaluated by specialists to determine the biota stress. The values that are not shaded were interpolated. The highest discharge representing a specific stress was used to define the integrated stress curve (**Figure 4.1**). In **Figure 4.1** the fish and macroinvertebrate stress index represents an integrated stress range between 0 – 1 and 6 – 10, i.e. the purple curve (representing the fish stress index) and the green curve (representing the invertebrate stress index) is lying below the integrated stress curve (black) for the dry season. For the wet season, the macroinvertebrate stress index represents the integrated stress range 1 - 7, therefore the red curve is lying below the integrated stress curve (black) (**Figure 4.1** – Wet season).

DRY SEASON **WET SEASON**

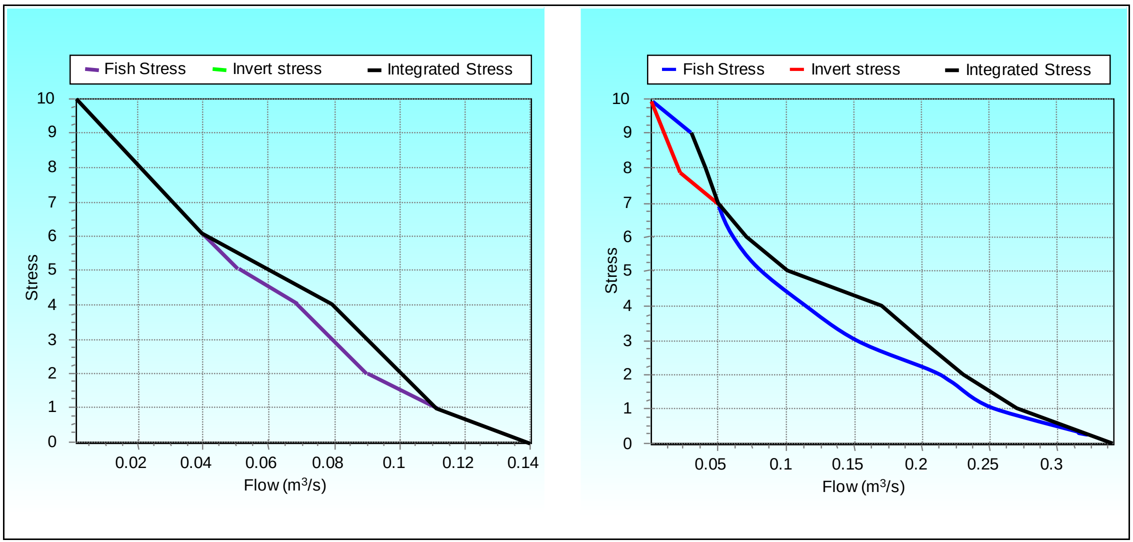

Figure 4.1: EWR 1: Species stress discharges used to determine biotic stress

Note that the integrated stress curve indicates or represents the most severe stress level experienced at each flow by the biota.

Table 4.1: EWR 1: Dry season species stress discharges used to determine biotic stress

Stress	Flow (m^3/s)		Integrated Flow (m^3/s)
	FISH	INVERTS	
0	0.14	0.14	0.14
1	0.11	0.11	0.11
2	0.09	0.1	0.1
3	0.08	0.09	0.09
4	0.07	0.08	0.08
5	0.05	0.06	0.06
6	0.04	0.04	0.04
7	0.03	0.03	0.03
8	0.02	0.02	0.02
9	0.01	0.01	0.01
10	0.001	0.001	0.001

Table 4.2: EWR 1: Wet season species stress discharges used to determine biotic stress

Stress	Flow (m^3/s)		Integrated Flow (m^3/s)
	FISH	INVERTS	
0	0.34	0.34	0.34
1	0.25	0.27	0.27
2	0.21	0.23	0.23
3	0.15	0.2	0.2
4	0.11	0.17	0.17
5	0.08	0.1	0.1
6	0.06	0.07	0.07
7	0.05	0.05	0.05
8	0.04	0.02	0.04
9	0.03	0.01	0.03
10	0.001	0.001	0

Tables 4.3 and **4.4** provide the summarised biotic response for the integrated stresses during the dry and wet season. Empty *response* blocks in tables indicate instances where too little resolution exists to estimate a response.

Table 4.3: EWR 1: Integrated stress and summarised habitat/biotic responses for the dry season

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or Biotic responses
0	0.14	Fish Inverts Maximum base flow – abundance of suitable habitat	**Fish:** Abundance of suitable critical habitat for semi-rheophilic sub-adult eels, *A. mossambica*, i.e. high amount of preferred FS (fast shallow) and SD (slow deep) habitat at these flows. Abundant cover, excellent connectivity in channel for eels and very good water quality at this flow. Maximum dry season populations of eels present throughout the Resource Unit. **Inverts:** The site was sampled at a flow close to this flow (0.16 m^3/s). Abundant preferred habitat for indicator taxa (13% comprises FCS[1], VFCS[2], FBR[3], VFBR[4]). There is sufficient **very fast** flow to maintain indicator taxa at an abundance indicative of a B category. The channel width of >4.5 m and average depth of 0.18 m ensures inundation of some instream vegetation (in flow) and fringing vegetation in the slow flowing areas and downstream pool. All flow-dependent invertebrates are catered for and water is well oxygenated. Marginal vegetation habitat quality is optimised in terms of inundation.
1	0.11	Fish Inverts	**Fish:** Instream biotopes plentiful and suitable for the selected flow-sensitive species, *A. mossambica.* Very similar to above, with virtually same eel population densities. **Inverts:** High habitat suitability for all sensitive rheophilic taxa with a preference for good water quality. Juveniles with a requirement for cover (e.g. certain mayflies) are able to utilise marginal vegetation in slow flowing and pool areas for cover. Average depth is 0.15 m and maximum depth 0.35 m. Sufficient fast and very fast flow.
2	0.1	Inverts	**Inverts:** Habitat suitability is still high. There is a reduction in **very fast** flows (relative to higher flows) which may have slight effect on the abundance of indicator taxa. There is ample **fast** flow to cater for the less sensitive rheophiles. Juveniles with a requirement for cover (e.g. certain mayflies) are able to utilise marginal vegetation in the slow flowing and pool areas for cover. Average depth of 0.15 m provides ample flow depth over boulders and cobbles to provide for simuliids.
3	0.09	Inverts	**Fish:** Reduced FS[5] and FD[6] habitats compared to higher flows. Good connectivity and water quality. Only slightly reduced population size compared to optimum.
4	0.08	Inverts	**Inverts:** There is a loss of very fast flows at this discharge. Over time this will reduce abundances in indicator taxa and other sensitive invertebrates with a preference for these flows (Tricorythidae and Psephenidae). Approximately 8% of the rocky habitat occurs in fast flow, and all rheophiles scoring <11 will be present in A-B abundances. A well-balanced community of invertebrates will be found under these conditions, assuming water quality remains good.
5	0.06	Inverts	**Fish:** Critical FS and FD habitat sufficient to maintain flow-sensitive eels, but becoming limiting and together with reduced connectivity causes population densities to drop moderately below potential maximum.
6	0.04	Inverts Fish	**Fish:** Critical habitat for flow-sensitive eel species is reduced and thus intraspecific competition for reduced habitat increases. Connectivity between pools is not possible at some critical riffles. Reduced food availability starts becoming limiting and water quality (low DO and temperatures) become problematic. Population numbers significantly reduced from optimum. **Inverts:** There is a significant reduction in fast flow. All rheophiles are still present, although abundances of the more sensitive taxa (Perlidae,

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or Biotic responses
			Heptageniidae, and Psephenidae) will be significantly reduced. Average and maximum depth are 0.1 and 0.27 m respectively, with a channel width of 3 m. Instream marginal vegetation (MV) is only just adequately inundated, with an average depth of 0.1 m. A narrow band of fringing vegetation is available in the downstream pool as cover for juveniles.
7	0.03	Inverts Fish	**Inverts:** Very little fast flow habitat remains (width of 0.1 m). Indicator taxa are likely to be absent at this flow, and abundances of all taxa scoring >10 will be reduced. The average depth of 0.1 m is likely to just maintain connectivity.
8	0.02	Inverts Fish	**Fish:** Critical FS and FD habitat severely limits eel abundance. Reduced cover and intraspecific competition is high and connectivity between pools is non-existent which exacerbates this problem. Water quality now impacting on health of eels. Marked reduction in numbers of indicator species (eels) apparent.
9	0.01	Inverts Fish	**Inverts:** No fast flow habitat remains. There is a gradual loss in connectivity. Only pools remain in the channel. Water temperature is likely to be low in pools (winter temperatures), however algae will increase due to elevated nutrient levels. Gradual loss of all rheophiles and other taxa scoring over 9.
10	0.001	Zero discharge, pools remain – habitat unsuitable for most biota	**Fish:** No suitable FS habitat is available for eels, and no longitudinal connectivity exists that allow eels to move to more suitable habitats. Poor water quality results in increased stress, disease and mortalities in eels. Low population numbers of eels survive. **Inverts:** Surface water only. Habitat is unsuitable for taxa scoring 9 or higher. Only resilient taxa remain in the system.

1: FCS – Fast over coarse substrate *2: VFCS - Very fast over coarse substrate*
3: FBR – Fast over bedrock *4: VFBR – Very fast over bedrock*
5: FS – Fast shallow *6: FD – Fast deep*

Table 4.4: EWR 1: Integrated stress and summarised habitat/biotic responses for the wet season

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or Biotic responses
0	0.34	Fish Inverts Maximum baseflow – abundance of suitable habitat	**Fish:** Abundance of highly suitable critical habitat for semi-rheophilic sub-adult eels, *A. mossambica*, i.e. high amount of preferred FS and SD habitat at these flows. Abundant cover, excellent connectivity in channel for eels and very good water quality at this flow. Maximum populations of eels present throughout RU. **Inverts:** Abundant preferred habitat for indicator taxa (21.6% comprises FCS, VFCS, FBR, VFBR). Channel width is >5 m and maximum depth is 0.48 m. All flow-dependent invertebrates are catered for and water is highly oxygenated. Marginal vegetation habitat quality is optimised in terms of inundation.
1	0.27	Inverts	**Fish:** Instream biotopes abundant and suitable for the selected flow-sensitive species, *A. mossambica.* Very similar to above, with virtually same eel population densities. **Inverts:** High habitat suitability for all sensitive rheophilic taxa with a preference for good water quality. Juveniles with a requirement for cover (e.g. certain mayflies) are able to utilise marginal vegetation in slow

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or Biotic responses
			flowing and pool areas for cover.
2	0.23	Inverts	**Inverts:** A maximum depth of 0.43 m relates to a high percentage (17%) of high to very high flow velocities over the critical habitat (cobbles, boulders). This provides ample habitat for the high-scoring rheophiles.
3	0.2	Inverts	**Fish:** Reduced FS and FD habitats compared to higher flows. Good connectivity and water quality. Only slightly reduced population size compared to optimum.
4	0.17	Inverts	**Fish:** Critical FS and FD habitat sufficient to maintain flow-sensitive eels, but starting to become limiting, thus population densities slightly below potential maximum. **Inverts:** The site was sampled at this flow. Abundance preferred habitat for indicator taxa (13% comprises FCS, VFCS, FBR, VFBR). There is sufficient **very fast** flow to maintain indicator taxa at an abundance indicative of a B category. The channel width of >4.5 m and average depth of 0.18 m ensures inundation of some instream vegetation and fringing vegetation in the slow flowing areas and downstream pool. All flow-dependent invertebrates are catered for and water is well oxygenated. Marginal vegetation is adequately inundated.
5	0.1	Inverts	**Fish:** Critical FS and FD habitat sufficient to maintain flow-sensitive eels, but starting to become limiting, thus population densities slightly below potential maximum. **Inverts:** Very fast flow (>6 m/s) disappears at this stress. The abundances of indicator taxa will be significantly reduced. Less sensitive rheophiles (scoring <10) are still catered for with fast flows (approx. 10% of habitat).
6	0.07	Inverts	**Fish:** Critical habitat for flow-sensitive eel species reduced, and thus intraspecific competition for reduced habitat increased. Connectivity between pools limited at critical riffles. Population numbers reduced from optimum. Reduced food availability starting to become limiting.
7	0.05	Fish Inverts	**Inverts:** Fast flow habitat is significantly reduced (only approx. 0.1 m in width). Indicator taxa and all sensitive rheophiles (scoring 10 and higher) likely to survive these conditions for a limited period (up to a week).
8	0.04	Fish	**Fish:** Critical FS and FD habitat severely limits numbers of eels, reduced cover and intraspecific competition is high. Connectivity between pools virtually non-existent. Marked reduction in numbers of indicator species (eels).
9	0.03	Fish	
10	0.001	Zero discharge, pools remain – habitat unsuitable for most biota	**Fish:** No suitable FS habitat available for eels, and no longitudinal connectivity allowing eels to move to more suitable habitats. Water quality is reduced leading to increased stress which results in disease as well as mortalities among eels. Low population numbers of eels survive. **Inverts:** Habitat unsuitable for taxa scoring 9 or higher. Only resilient taxa remain in the system.

5 EWR 1 (XURA RIVER): DETERMINATION OF EWR SCENARIOS

5.1 ECOCLASSIFICATION: SUMMARY OF EWR 1

Table 5.1 summarizes the EcoClassification state and Recommended Ecological Category for EWR 1.

Table 5.1: Output of the EcoClassification process for EWR 1 on the Xura River

EWR 1					
EIS: MODERATE Highest scoring metrics used to assess EIS, were unique instream species, diversity of instream and riparian habitat types, presence of critical instream refuges and important riparian migration corridors. **PES: B** Trampling and limited erosion (cattle). Increased nutrient levels (cattle, human waste and clothes washing). Alien vegetation. **REC: B** EIS was MODERATE and the REC is therefore to maintain the PES. **AEC: C** A hypothetical deteriorated situation was characterised by decreased flows and the resulting responses to this situation.	Driver Components	PES & REC	Trend	AEC ↓
	IHI HYDROLOGY	A/B		
	WATER QUALITY	A/B		B/C
	GEOMORPHOLOGY	A/B		C
	Response Components	PES	Trend	AEC↑
	FISH	A/B	0	B/C
	MACRO INVERTEBRATES	A/B	0	B/C
	INSTREAM	A/B	0	B/C
	RIPARIAN VEGETATION	B/C	0	C
	ECOSTATUS	B		C
	INSTREAM IHI	A/B		
	RIPARIAN IHI	B		
	EIS	MODERATE		

5.2 HYDROLOGICAL CONSIDERATIONS

The wettest and driest months were identified as November and August respectively. Droughts were set at 95% exceedence (flow) and 5% exceedence (stress). Maintenance flows were set at 40% exceedence (flow) and at 60% exceedence (stress).

5.3 LOW FLOW REQUIREMENTS (IN TERMS OF STRESS)

The integrated stress index was used to identify required stress levels at specific durations for the wet and dry months/seasons.

5.3.1 Low Flow (in terms of stress) Requirements

The flow requirements for different Ecological Categories (ECs) are provided in **Table 5.2** and graphically illustrated in **Figure 5.1**. The results were plotted for the wet and dry seasons on stress duration graphs and compared to the Desktop Reserve Model (DRM) low flow estimates for the same range of ECs. The stress requirements (as a 'hand drawn line') are illustrated in **Figure 5.1**. For easier reference the range of ECs are colour coded in the following tables and figures:

PES and REC: **Purple** AEC↓: **Green**

Summarised motivations for the final requirements are provided in **Table 5.3**.

Table 5.2: EWR 1: Species and integrated stress requirements as well as the final integrated stress and flow requirement

Stress Duration	Fish Stress	Fish Flow	Invertebrate Stress	Invertebrate Flow	FINAL* (Integrated stress)	Flow requirement (m^3/s)
PES (Instream): A/B ECOSTATUS			FISH: A/ B		MACROINVERTEBRATES: A/B	
DRY SEASON						
5%	9	0.01	9	0.01	9	0.01
20%	8.1	0.019	8.1	0.019	8.1	0.019
40%	5.5	0.049	5.5	0.048	5.5	0.049
WET SEASON						
5%	7	0.05	7.7	0.03	7	0.05
20%	6	0.06	5.6	0.08	5.7	0.08
40%	4.7	0.09	4.6	0.13	4.6	0.13
AEC↓ (Instream): B/C ECOSTATUS			FISH: B/C		MACROINVERTEBRATES: B/C	
DRY SEASON						
5%	9	0.01	9	0.009	9	0.01
20%	8.25	0.018	8.5	0.015	8.2	0.018
40%	6.5	0.035	7	0.03	6.5	0.035
WET SEASON						
5%	8.4	0.04	8	0.019	8	0.04
20%	6.5	0.055	6.6	0.055	6.7	0.055
40%	5	0.08	5	0.1	5	0.1

** Final refers to the final stress selected as the EWR requirement, i.e. the lowest integrated stress.*

DRY SEASON (August) **WET SEASON (November)**

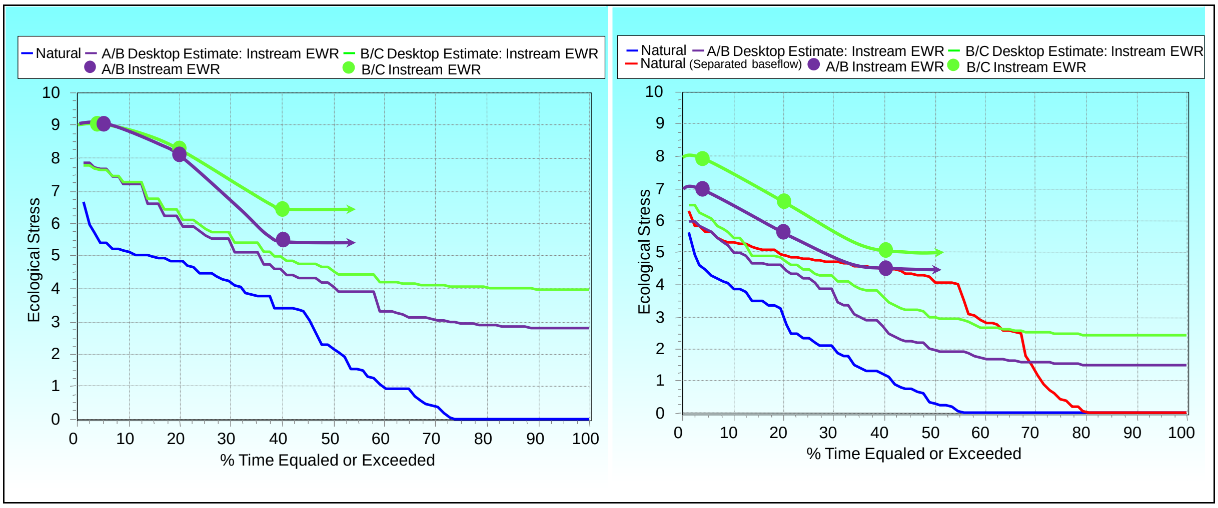

Figure 5.1: EWR 1: Stress duration curve for a PES, REC and AEC↓

Table 5.3: EWR 1: Summary of motivations

Month	% Stress duration	Component stress[1]	Integrated stress	Flow (m^3/s)	Comment
PES (Intsream): A/B ECOSTATUS					**FISH: A/ B MACROINVERTEBRATES: A/B**
Aug	5% drought	F&I 9	9	0.01	**Fish:** At this flow no passage for eels or fish is present. Preferred riffle eel habitat is absent and water quality not optimal leading to elevated natural mortalities. However, these impacts are mitigated due to low water temperatures and limited fish and eel movement during winter. **Invertebrates:** Conditions will result in the loss of flow dependent indicator (FDI) taxa, however – assuming temperatures to be moderate - the adequate depth and velocity (oxygenation) should enable eggs to persist and thus hatching of indicator taxa to occur in summer.
	20%	F&I 8.1	8.1	0.019	**Fish:** No passage for fish is present while limited for eels. Very limited preferred riffle habitat for eels, but impacts mitigated to some degree in winter months. Water quality adequate. A slight increase in natural mortalities is expected. **Invertebrates:** Under these slow flow conditions with sufficient depth, indicator taxa with a preference for fast and very flows will be absent (or present in very low abundances). However the conditions should enable eggs to persist so that the population should recover under wet season baseflow conditions.
	40%	F&I 5.5	5.5	0.049	**Fish:** Moderate rifle habitat available and passage for eels while limited for other fish. Water quality suitable and no elevated mortalities are expected. **Invertebrates:** There is adequate depth and velocity over rock surfaces to maintain all FDIs but for those with a preference for very high velocities (>0.6m/s).
Nov	5% drought	F 7	7	0.05	**Fish:** Limited eel passage and preferred habitat in riffles, very limited passage between pools for small fish. Water quality could be problematic (low DO and high temperatures) in hot months. Slightly elevated natural mortalities expected.
	20%	I 5.6	5.6	0.08	**Invertebrates:** At this discharge the hydraulic model indicates that no very fast flow habitats occur. It is however likely, with the depth of flow over rock surfaces, and the width associated with this flow, that these taxa will persist for this restricted period, and could increase in number when conditions become favourable.

Month	% Stress duration	Component stress[1]	Integrated stress	Flow (m^3/s)	Comment
	40%	I 4.6	4.6	0.13	**Invertebrates:** At this discharge the maximum modelled velocity is 0.6 m/s which is required for the FDIs to persist in satisfactory breeding condition and at healthy abundances.
AEC↓ (Instream): B/C ECOSTATUS			**FISH: B/C**		**MACROINVERTEBRATES: B/C**
Aug	5% drought	F&I 9	9	0.01	**Fish:** At this flow no passage for eels or fish are present. Preferred riffle eel habitat is absent and water quality not optimal, thus elevated natural mortalities are present. These impacts are slightly mitigated due to low water temperatures and limited fish and eel movement during winter.
	20%	F 8.25	8.25	0.18	**Fish:** No passage for fish is present while very limited passage for eels exists. Very limited, if any, preferred riffle habitat available for eels, but these impacts are not that critical in winter months. Water quality adequate. An increase in natural mortalities is expected.
	40%	F 6.5	6.5	0.035	**Fish:** Limited riffle habitat available and moderate passage for eels is present although limited for other fish. Water quality suitable and no elevated mortalities are expected.
Nov	5% drought	F 8.4	8	0.04	**Fish:** Very limited eel passage and preferred eel habitat in riffles is present with very limited, if any, passage between pools for small fish. Water quality probably problematic (low DO and high temperatures) in hot months. Elevated natural mortalities expected.
	20%	F: 6.5 I: 6.6	6.6	0.055	**Fish:** Moderate rifle habitat available and passage for eels, however, limited passage for fish is available. Water quality suitable and no elevated mortalities expected.
	40%	I: 5	5	0.1	**Invertebrates:** At this discharge there will be narrow areas of Very Fast Flow over Coarse Substrates (VFCS), enabling most of the sensitive FDIs to survive, however abundances will be lower than in the A/B state, and breeding of these taxa could be negatively affected.

1: Component stress indicated as either an F for fish or I for invertebrates.

5.3.2 Final Low Flow Requirements

To produce the final low flow EWR results, the DRM results for the specific category were modified according to specialist requirements provided and shown in **Figure 5.2**. There are a range of options one can use to make these modifications, such as changing the annual EWR, specific monthly volumes, either drought or maintenance flow durations, seasonal distribution and changing the category rules and shape factors. There were no specialist requirements for changes to rules in the DRM governing wet and dry seasons. The following changes were required:

PES and REC (instream): A/B

- Maintenance seasonal distributions set to 1.37;
- Adjust Maintenance Low Flow set to 22.49%;
- Drought seasonal distributions set to 4.46;
- Adjust Drought Low Flow set to 5.70%;
- Wet season rules:

- No changes; and

- Dry season rules:

  - No changes.

AEC↓ (instream): B/C

- Maintenance seasonal distributions set to 1.67;
- Adjust Maintenance Low Flow set to 16.19%;
- Drought seasonal distributions set to 3.06;
- Adjust Drought Low Flow set to 4.75%;
- Wet season rules:

  - No changes; and

- Dry season rules:

  - No changes.

DRY SEASON (August) **WET SEASON (November)**

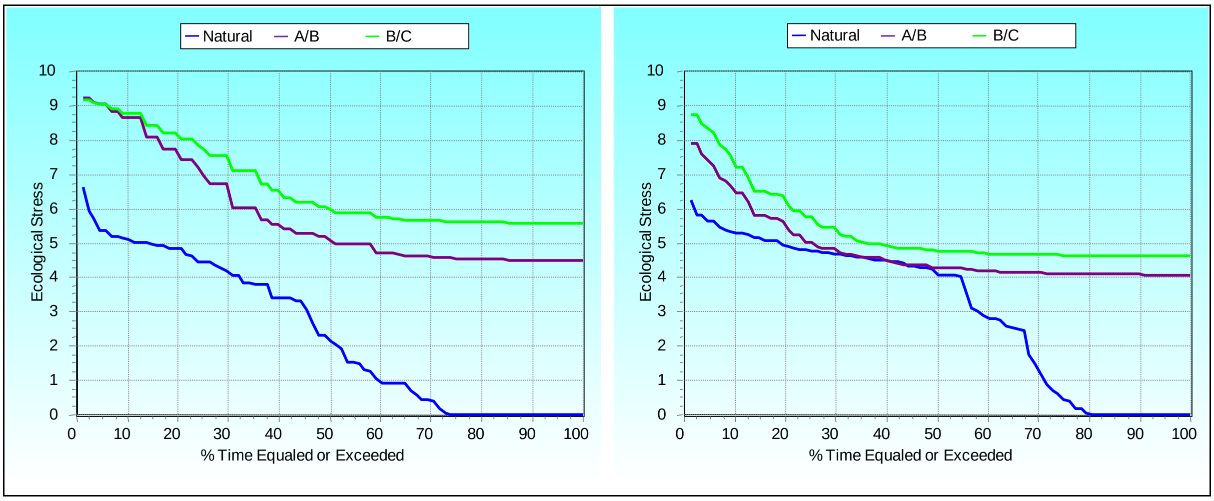

Figure 5.2: EWR 1: Final stress requirements for low flows

5.4 High Flow Requirements

The high flow classes were identified as follows:

- The geomorphologist and riparian vegetation specialist identified the range of flood classes required and listed the functions of each flood;
- The instream specialists then indicated which of the instream flooding functions were addressed by the floods identified for geomorphology and riparian vegetation (indicated by a ✓ in **Table 5.4**); and

- Any of the floods required by the instream biota and not addressed by the floods already identified, were then described (in terms of ranges and functions) for the instream biota.

Final high flow results are provided in **Table 5.4**. Note that AVE is used as an acronym for Average.

Table 5.4: EWR 1: Identification of instream functions addressed by the identified floods for geomorphology and riparian vegetation

FLOOD RANGE (m³/s) FLOOD CLASS	Geomorphology and riparian vegetation motivation	Fish flood functions						Invertebrate flood functions						
		Migration cues & spawning	Migration habitat (depth etc.)	Clean spawning substrate	Create nursery areas	Resetting water quality	Inundate vegetation for spawning	Breeding and hatching cues	Clear fines	Scour substrate	Reach or inundate specific areas	Sorting coarse substrates	Transport; migration cues for shrimps	Clear + inundate MV and fringing veg e.g. for shelter (juveniles)
0.4 - 0.6 (m^3/s) 0.4 (AVE)	**Geomorph:** This flow class removes fines and cleans the small gravels on the bed of the active channels. **Riparian Veg:** To inundate areas a range between 0.4 and 0.6 m^3/s is needed with regard the higher marginal zones and the upper zone (height 0.5 - 0.6 m). Maintenance of instream vegetation that requires wet to moist soil conditions. Flood volumes will reach the upper banks/terraces to firstly remove the woody components (alien vegetation), thus keeping the area in a near natural state i.e. shrubs and grasses.	√	√	√	√	√	√	√	√	√	√	√		√
1 - 2 m^3/s 1 (AVE)	**Geomorph:** This flow class removes fines and cleans the small gravels on the bed of the active channels. **Riparian Veg:** Ensures maintenance of lower zone vegetation that requires short periods of inundation over life cycle (2 -3 times a year). Flood range 1 - 2 m^3/s or height of 0.7 - 0.9 m.	√	√	√	√	√	√	√	√	√	√			√
3 - 3.9 m^3/s 3 (AVE)	**Geomorph:** This flow class (daily average of 3) activates the small gravels (20 mm size) on the bed of the active channels, and is also responsible for transporting more than 20% of the fines. **Riparian Veg:** Ensures removal of woody component, which in this case reduces the overall alien plant cover. Flood range 3 - 3.9 m^3/s or height of 1 - 1.1 m.	√	√	√	√	√	√	√	√	√	√	√	√	√
7.9 - 9 m^3/s 8 (AVE)	**Geomorph:** This is the effective discharge class for the fines and small gravels, accounting for about 30% of the transport of sands and 40% of the small gravels. This discharge class also corresponds with the terraces at the site. **Riparian Veg:** Maintains the natural woody vegetation that remains in small pockets along the length of the system that require moist soil conditions (at least once a year). Flood range of 7.9 - 9 m^3/s or height of 1.36 to 1.4 m.	√	√	√	√	√	√	√	√	√	√	√	√	√

The number of high flow events required for each EC is provided in **Table 5.5**. The availability of high flows was verified using the observed data at gauge T6H004.

Table 5.5: EWR 1: The recommended number of high flow events required

FLOOD RANGE (m^3/s) FLOOD CLASS	INVERTS	FISH	VEGETATION	GEOMORPH	FINAL	MONTHS	DAILY AVERAGE	DURATION
PES and REC (instream): A/B ECOSTATUS								
0.4 - 0.6	3	5	2	5	5	Jan, Feb, Mar, Oct, Dec	0.4	3
1 – 2	2	5	2	5	5	Jan, Feb, Oct, Nov, Dec	1	3
3 - 3.9	1	1	1:1	1	1	March	3	4
7.9 – 9			1:2	1	1*	Nov	8*	4
** 8 is the 1:1 year flood under natural conditions*								
AEC↓ (instream): B/C ECOSTATUS								
FLOOD RANGE (m^3/s) FLOOD CLASS	**INVERTS**	**FISH**	**VEGETATION**	**GEOMORPH**	**FINAL***	**MONTHS**	**DAILY AVERAGE**	**DURATION**
0.4 - 0.6	2	4	1	4	4	Feb, Mar, Oct, Dec	0.4	3
1 - 2	1	4	1	4	4	Jan, Feb, Nov, Dec	1	3
3 - 3.9	1	1	1:2	1:1	1:1	March	3	4
7.9 - 9			1:4	1:2	1:2**	Nov	8	4

** Final refers to the agreed on number of events considering the individual requirements for each component.*

*** Refers to frequency of occurrence, i.e. the flood will occur once in two years.*

5.5 FINAL FLOW REQUIREMENTS

The low and high flows were combined to produce the final flow requirements for each EC as:

- An EWR table, which shows the results for each month for high flows and low flows separately (**Tables 5.6** and **5.7**); and
- An EWR rule table which provides the recommended EWR flows as a duration table, linked to a natural trigger (natural modelled hydrology in this case). EWR rules were supplied for total flows as well as for low flows only (**Tables 5.8** and **5.9**).

The rule curve is useful for water resources modelling, whilst the EWR table provides information on the MAR at the EWR as well as the EWR required, category and rule curve definition. The information on the EWR is broken down to show the split between high and low maintenance flows, and also provide drought flows.

Table 5.6: EWR 1: EWR table for PES and REC (instream): A/B

Desktop version:		2	Virgin MAR (million m^3)		14.166	
BFI	0.425	Distribution type			T Reg Coast	
MONTH	LOW FLOWS		HIGH FLOWS (m^3/s)			
	Maintenance (m^3/s)	Drought (m^3/s)	Instantaneous peak	Daily average (incl. baseflow)	Daily average (excl. baseflow)	Duration (days)
OCTOBER	0.088	0.02	0.4 – 0.6 1 - 2	0.4 1	0.312 0.912	3 3
NOVEMBER	0.136	0.04	1 – 2 7.9 - 9	1 8	0.864 7.864	3 4
DECEMBER	0.127	0.037	0.4 – 0.6 1 - 2	0.4 1	0.273 0.873	3 3
JANUARY	0.11	0.03	0.4 – 0.6 1 - 2	0.4 1	0.290 0.89	3 3
FEBRUARY	0.132	0.037	0.4 – 0.6	0.4	0.268	3
MARCH	0.14	0.042	0.4 – 0.6 3 – 3.9	0.4 3	0.260 2.860	3 4
APRIL	0.121	0.034				
MAY	0.086	0.02				
JUNE	0.076	0.015				
JULY	0.075	0.015				
AUGUST	0.059	0.008				
SEPTEMBER	0.065	0.01	1 - 2	1	0.935	3
TOTAL million m^3	3.186	0.807	2.863			
% OF VIRGIN (natural)	22.49	5.70	20.21			
Total EWR	6.048					
% of MAR	42.7					

Table 5.7: EWR 1: EWR table for AEC↓ (instream): B/C

Desktop version:		2	Virgin MAR (million m³)		14.166	
BFI	0.425	Distribution type			T Reg Coast	
MONTH	LOW FLOWS		HIGH FLOWS (m³/s)			
	Maintenance (m³/s)	Drought (m³/s)	Instantaneous peak	Daily average (incl baseflow)	Daily average (excl baseflow)	Duration (days)
OCTOBER	0.062	0.017	0.4 – 0.6	0.4	0.338	3
NOVEMBER	0.101	0.032	1 – 2 7.9 - 9	1 8	0.899 7.899 (1:2 years)	3 4
DECEMBER	0.094	0.03	0.4 – 0.6 1 – 2	0.4 1	0.306 0.906	3 3
JANUARY	0.08	0.024	1 - 2	1	0.920	3
FEBRUARY	0.097	0.03	0.4 – 0.6	0.4	0.303	3
MARCH	0.104	0.034	0.4 – 0.6 3 – 3.9	0.4 3	0.296 2.896	3 4
APRIL	0.089	0.028				
MAY	0.061	0.017				
JUNE	0.053	0.014				
JULY	0.052	0.013				
AUGUST	0.039	0.008				
SEPTEMBER	0.043	0.01	1 - 2	1	0.990	3
TOTAL million m³/a	2.294	0.673	2.009			
% OF VIRGIN (natural)	16.19	4.75	14.9			
Total EWR	4.303					
% of MAR	30.38					

Table 5.8: EWR 1: Assurance rules (m³/s) for PES and REC (instream): A/B

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.183	0.182	0.179	0.172	0.16	0.139	0.109	0.073	0.042	0.028
Nov	1.334	1.179	0.926	0.509	0.324	0.266	0.235	0.216	0.174	0.104
Dec	0.281	0.263	0.248	0.232	0.215	0.185	0.158	0.118	0.073	0.045
Jan	0.206	0.206	0.204	0.199	0.191	0.175	0.149	0.11	0.066	0.038
Feb	0.176	0.176	0.174	0.171	0.163	0.15	0.129	0.098	0.062	0.04
Mar	0.573	0.519	0.472	0.325	0.254	0.213	0.183	0.161	0.115	0.06
Apr	0.145	0.144	0.142	0.137	0.128	0.113	0.092	0.067	0.045	0.035
May	0.103	0.102	0.1	0.097	0.09	0.079	0.063	0.044	0.028	0.021
Jun	0.091	0.09	0.089	0.085	0.079	0.069	0.054	0.037	0.022	0.015
Jul	0.09	0.089	0.087	0.084	0.078	0.067	0.053	0.036	0.022	0.015
Aug	0.07	0.07	0.069	0.066	0.061	0.052	0.04	0.026	0.014	0.008
Sep	0.139	0.138	0.136	0.131	0.121	0.104	0.08	0.052	0.028	0.016

Table 5.9: EWR 1: Assurance rules (m^3/s) for AEC↓ (instream): B/C

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.098	0.098	0.096	0.093	0.087	0.076	0.061	0.042	0.027	0.019
Nov	0.768	0.683	0.609	0.509	0.324	0.266	0.235	0.216	0.131	0.068
Dec	0.254	0.235	0.219	0.203	0.187	0.159	0.135	0.101	0.063	0.038
Jan	0.159	0.159	0.157	0.154	0.147	0.135	0.115	0.086	0.052	0.03
Feb	0.142	0.142	0.141	0.138	0.132	0.122	0.104	0.079	0.051	0.033
Mar	0.544	0.489	0.441	0.325	0.254	0.213	0.183	0.161	0.104	0.057
Apr	0.11	0.109	0.108	0.104	0.098	0.087	0.071	0.052	0.036	0.029
May	0.075	0.075	0.074	0.071	0.067	0.059	0.047	0.034	0.023	0.017
Jun	0.065	0.065	0.064	0.062	0.058	0.051	0.041	0.029	0.019	0.014
Jul	0.064	0.064	0.063	0.06	0.056	0.049	0.039	0.028	0.018	0.013
Aug	0.048	0.048	0.047	0.045	0.042	0.036	0.029	0.02	0.012	0.008
Sep	0.117	0.116	0.114	0.11	0.102	0.088	0.069	0.046	0.026	0.016

A comparison between the Desktop Reserve Model estimates and the EWR results in terms of percentages of natural flow are provided in **Table 5.10**.

Table 5.10: EWR 1: Modifications made to the DRM (%)

Changes	PES and REC (instream): A/B		AEC↓ (instream): B/C	
	DRM	EWR	DRM	EWR
ML EWR - Maintenance low flow	22.96	22.49	14.42	16.19
DL EWR - Drought low flow	4.77	5.70	4.77	4.75
MH EWR - Maintenance high flow	14.76	20.21	11.52	14.19
Long-term % of virgin (natural) MAR	34.16	36.79	25.02	28.71

6 EWR 1 (XURA RIVER): OPERATIONAL SCENARIOS

This document outlines the approach taken for Step 4 of the EWR or Preliminary Reserve process, i.e. defining operational scenarios for Zalu Dam and determining the ecological consequences of the scenarios. This chapter should be read in conjunction with *Appendix K* of the *Water Resources Assessment Report* for the DWA study (DWA, 2013), which describes the scenarios and modelling undertaken. Details such as catchment description and hydrological background can also be found in this document.

6.1 RIVER REACHES

The focus is on the EWR 1 site of the Xura River downstream of the proposed dam, and two stretches immediately below the site. **Figure 6.1** shows the stretches and present state of each reach. As EWR 2 is on the Msikaba River, which is too far downstream of the dam to be managed by operation of the dam, the focus of this chapter is on EWR 1.

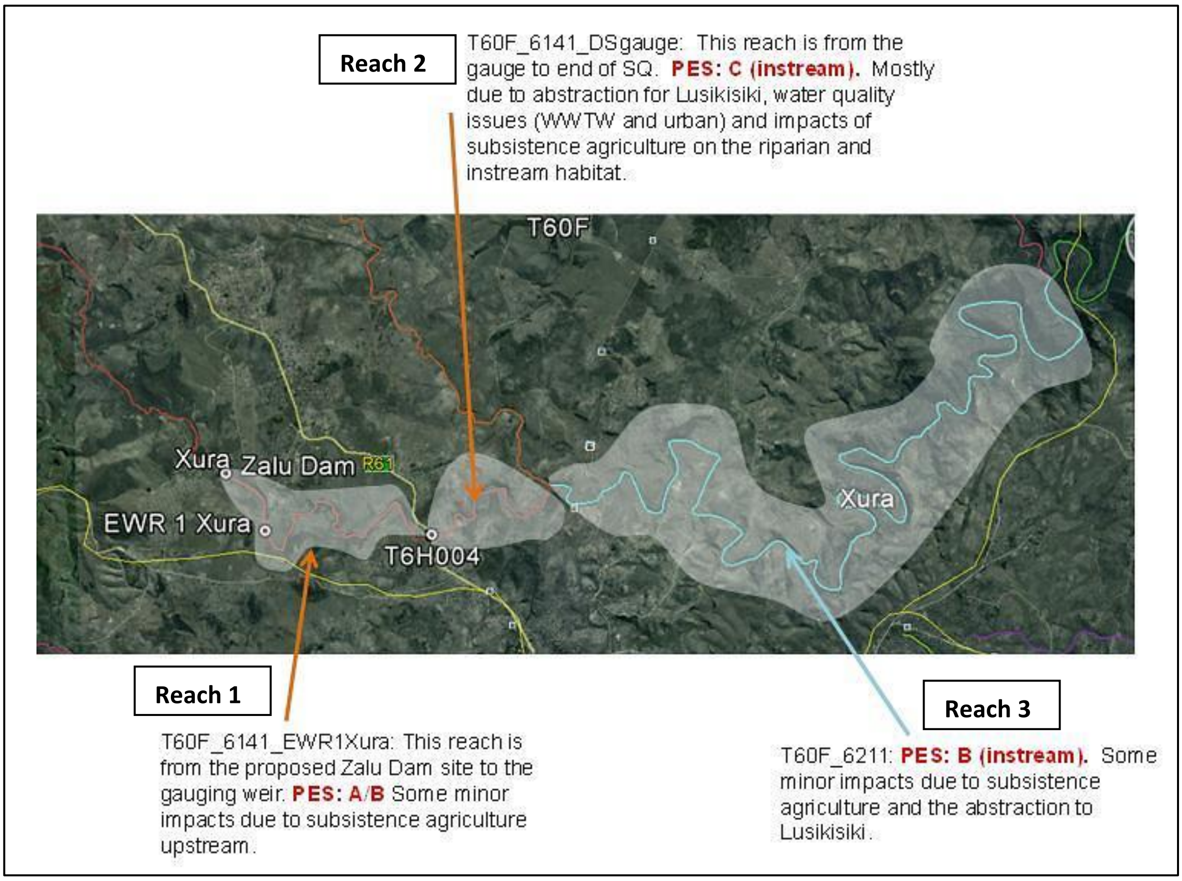

Figure 6.1: Reaches of the Xura River assessed during scenario evaluation

Note that the PES assessment for the EWR 1 was conducted during the *Reserve Study*, while the instream PES categories for the reaches downstream are estimates, as provided by another study conducted by Scherman Colloty & Associates at the same time (i.e. the *DWA/WRC Present Ecological State Desktop Study: WMA12 and WMA15* (Birkhead et al., 2013)). The reaches will be named as follows for the purposes of this report:

- Reach 1: downstream Zalu Dam to the gauging weir (T6H004), including EWR 1.
- Reach 2: downstream gauging weir to upstream of the inflow of the Xurana River, including impacts from Lusikisiki town.
- Reach 3: from the Xurana confluence to the Msikaba confluence, including the inflows of the Xurana River.

6.2 SCENARIOS

The following information was taken from the *Water Resources Assessment Report* (DWA, 2013) of Ms E van Niekerk, AECOM, the hydrologist/modeller for the study; and describes the scenarios evaluated by the ecological team. More detail can be found in said report.

The latest version of the Water Resource Yield Model (WRYM) incorporated in the Water Resource Information Management System (WRIMS), version 3.8.2, was used to simulate the behaviour of the Xura River and the water users under various development scenarios. EWRs were required at the outlets of:

- Reach 1 (incl. EWR 1): instream Category A/B;
- Reach 2: instream Category C; and
- Reach 3: instream Category B.

The incremental catchment run-off downstream of the proposed Zalu Dam is presently in a near-natural state with no significant land-use. The Zalu Dam run-off will also constitute less than 20% of the Xura River catchment run-off. It was therefore assumed that the frequency and magnitude of floods and freshets in the Xura River downstream of the confluence with the Xurana River will be adequate without any additional releases from Zalu Dam. The floods and freshets at EWR 1 were however included in the analysis of the river reach downstream of Zalu Dam.

6.2.1 Scenario Selection

Scenarios to reflect the most probable future developments were created in consultation with the DWA. Scenario selection was an iterative process, with the scenarios selected for the ecological consequences analysis only investigating domestic releases via the river. This was based on yield analysis demonstrating the benefit of releases from the dam and abstraction from the weir. Irrigation abstraction was assumed to be directly from Zalu Dam. The scenarios selected for analysis are shown in **Table 6.1** (DWA, 2013).

Table 6.1: Proposed scenarios to determine the ecological consequences of the proposed developments

Scenario	Zalu Dam 607.5 m 4.89 million m^3	Zalu Dam 610.2 m 6.53 million m^3	Zalu Dam 611.5 m 7.64 million m^3	Zalu Dam 614.5 m 10.19 million m^3	Domestic abstraction at T6H004 million m^3/a	Irrigation direct from Zalu dam million m^3/a
1	√				4.47	
2		√			5.40	
3			√		4.47	1.452
4				√	5.40	1.452

Note that Scenarios 2 and 3 are very similar, with insufficient resolution to distinguish between them in terms of ecological impact. Only Scenarios 1 and 4 were therefore evaluated by the Reserve team. The analyses reflect on the flow in the river relating to the proposed development scenarios to study the impact thereof if no water at all is implicitly released to meet the Reserve requirements.

Low flow, high flow and seasonality graphs can be viewed in DWA (2013). Only ecological consequences of scenarios are discussed in this document.

6.3 ECOLOGICAL CONSEQUENCES OF SCENARIOS

The section below describes consequences of scenarios for driver and biotic responses, as well as impacts of releases on low and high flows.

6.3.1 Low Flows

Yield modelling indicates that the EWRs are met at all reaches during the dry season. Concerns were as follows. **Modelling results/recommendations are shown in bold.**

- Releases may result in flows being more than natural at EWR 1 due to the constant release from Zalu Dam. **The modelling showed that releases did not result in flows that were more than natural**.
- Constant releases may impact on seasonality. **Modelling shows that a total monthly flow volume is still maintained due to the variability of the floods and high flows**

coming over the dam wall. However, there is concern that the continuous baseflow with little variability in the baseflows might be a concern for instream biota.

As the instream specialists (i.e. for fish and macroinvertebrates) do not have the resolution (especially without the scenarios disaggregated into daily flows), to quantitatively indicate what the impact of constant releases will be, they were requested to provide a generic or narrative description of what the consequences could be on the instream biota under the following conditions: (1) constant baseflows during all months, with minimal variation between months and within months; (2) consider the impact of minimum drought flows; and (3) conduct the assessment under the worst case scenario (i.e. Scenario 4), which considers water use at the full development stage of rural water supply.

a) Macroinvertebrates

This section of the report was authored by Dr Mandy Uys of Laughing Waters, who served as the macroinvertebrate specialist for the study.

Scenario 4 amounts to releases for a supply for domestic use (i.e. including agricultural activities) of 6.852 million m^3/a (Pieterse, AECOM, pers. comm., March 2013). Assuming a constant release, this equates to a regulated flow of approximately 0.22 m^3/s. This discharge is associated with the following modelled hydraulic habitat parameters for invertebrates, as provided by the hydraulician for the study, Dr Andrew Birkhead.

- Average depth: 0.21 m
- Maximum depth: 0.42 m
- Average velocity: 0.22 m/s
- Max velocity: 0.71 m/s

The modelled distribution of **macroinvertebrate** flow habitats (in percentages of total habitat), is therefore as follows:

Habitat type	VSCS	SCS	FCS	VFCS	VSFS	SFS	FFS	VFFS	VSBR	SBR	FBR	VFBR	VEG
% habitat type	8	10	5	1	5	7	3	1	14	17	9	2	19

** V= Very; S= Slow; F= Fast; C= Coarse; F= Fine; S= Substrate; BR = Bedrock; Veg= Vegetation*

The low confidence estimated consequences of flow regulation for EWR 1 and Reach 1, as related to macroinvertebrates, were as follows:

Wet Season (low flow data only): A regulated discharge of 0.22 m^3/s is associated with optimal habitat and a low invertebrate stress of 2 out of 10. These flows would normally be experienced during mid-Wet Season.

Wet Season, Initial changes: Assuming that marginal and instream vegetation remain intact (under predicted scour conditions), water quality remains in a good state, and water temperature is within a normal range, instream habitat should be plentiful and diverse. Marginal and instream vegetation will be inundated to a depth of >10 cm at these flows and will provide substantial flow and non-flow habitat, and refuge for developing juveniles. All fast-flow biotopes will be activated, maintained and plentiful, with diverse and abundant invertebrate inhabitants. Slow-flow biotopes will also be well represented, such that taxa with a preference for these habitats should also persist in good abundance. Overall, an increase in diversity and abundance of the current taxa could occur.

Wet Season, Over time: Within the first few years after the commencement of dam operation, the loss of early summer high flows and floods due to the impounding effect of the dam wall (particularly under Scenario 4) may represent a loss of – or interference with – natural breeding or emergence cues in some taxa. Once the predicted changes to geomorphology and riparian vegetation occur (i.e. bed-armouring, reduction in instream and riparian vegetation, channel deepening or widening in places) there is likely to be a decrease in the abundance of indicator taxa with a preference for either moderate and fast flows and cobble habitat, or marginal vegetation type habitat. Over time these taxa will become rarer and some may disappear. The loss of marginal vegetation also represents a loss of cover for juveniles during summer months. A shift in community structure over time is likely.

Dry Season (low flow data only): The discharge of 0.22 m^3/s is well in excess of the Dry Season zero-stress discharge of approximately 0.14 m^3/s. While it is difficult to specify the outcomes of sustained high flows during the dry season to the invertebrate community, the following principles apply: under natural conditions, winter dry season low flow conditions limit habitat availability and diversity, thereby regulating populations; and the usual seasonal decrease (and summer increase) in flows provide important life-cycle cues to invertebrates which are effectively lost under regulated, raised flow conditions.

Dry season, Initial changes: A shift in community structure is likely, initially favouring taxa which have a preference for clear, moderate to fast flowing water, such as Perlid stoneflies and Heptageniid mayflies, and disadvantaging taxa with a preference for instream or marginal vegetation.

Dry season, Over time: The predicted geomorphological and riparian zone changes associated with the Wet Season are likely to result in a substantial reduction in habitat availability and thus in the abundance of both indicator taxa and the other sensitive habitat-dependent taxa (scoring 7-10 on the SASS5 scale).

Additional changes may mirror those observed in other river systems exposed to regulated flow conditions: e.g. change in population structure and species composition, excessive growth of aquatic macrophytes, the potential for pest species to proliferate, and reduced diversity of macroinvertebrates over time (Bunn and Arthington, 2002). As an example: in the Great Fish River in the Eastern Cape, which is naturally temporary, imported and regulated flows from the Orange River for the past 3-4 decades have altered the water quality, sediment regime, channel form, and instream habitat of the river to the extent that the community structure of the aquatic invertebrates has entirely changed, resembling that of a perennial system. In addition, the import of water has resulted in the import and proliferation of *Simulium chutteri*, a pest blackfly which causes night blindness in cattle.

b) Fish

This section of the report was authored by Dr Anton Bok of Anton Bok Aquatic Consultants, who served as the fish specialist for the study.

Assumptions

- There are no significant or large tributary inflows into Reach 1 below Zalu Dam.
- Due to lower winter rainfall spills from the dam and thus smaller floods, the provision of important cues to biota by these flows in Reach 1 are expected to be delayed by a month or two (e.g. from September/October/November to December or January in a "normal" year).
- Although dam spills will occur and ensure elevated flows downstream, the size and frequency of these spills will be reduced by the dam.
- Large floods in Reach 1 will not be affected by the dam.

Potential Impacts on Fish

- The main potential impacts will be related to reducing the breeding success of *Barbus* "Transkei" n. sp. (Transkei barb) and possibly disrupting the normal migratory behaviour of eels.
- Transkei barbs spawn on clean, newly flooded marginal and instream vegetation mainly in spring (and summer). High-flow events trigger and synchronise mass spawning behaviour, which increases spawning success at a time when optimum spawning substrate for the adhesive eggs is inundated by elevated water levels.
- The optimum time for spawning, larval growth and survival is considered to be in spring when productivity is high and food for fish larvae is abundant and water quality is good.
- The capture of the early spring high flows by Zalu Dam will probably delay mass spawning in the river downstream, resulting in reduced breeding success. **Note that the capture of these high flows is dependent on whether the dam is full or not**.
- A reduction in the normal number of high flows during the summer breeding period due to the presence of the dam will reduce the number of spawning events, and thus breeding success of the Transkei barb. **Note that the capture of these high flows is dependent on whether the dam is full or not**.
- The migratory behaviour of eels (e.g. AMOS (*Anguilla mossambica*)) is thought to be triggered by high flows when instream barriers (e.g. rapids and waterfalls) are flooded out, facilitating upstream migration. **Any reduction in floods or elevated river flows will thus impact negatively on migration.**
- **The smallest dam (Scenario 1) with more frequent spills and more natural hydrology, compared to the impact of larger dams, is thus the most desirable ecological option for fish.**
- The constant release of baseflows which will be more consistent and elevated at times relative to present day conditions, should not have serious negative impacts on the fish fauna if falling within the natural range of baseflows in the reach.
- The clearwater (sediment free) releases from the dam, causing increased bed and bank scour at EWR 1, may reduce the extent of instream macrophytes and marginal vegetation, reducing the availability of spawning substrate for *Barbus* sp. and thus reducing breeding success.
- The increased scouring from dam releases could clean fine sediment from riffles and rapids, improving these habitats as substrate cover for eels (AMOS), as well as for small *Barbus* (BANO (*Barbus anoplus*)).

The following comments are added as to why a typical fishway is not required: only two fish species are present - *Barbus* "Transkei" n. sp. (Transkei barb) and eels (*Anguilla mossambica)* and maybe *A. marmorata*, or *A. bicolor bicolor.* As the Barbus only migrate small distances to suitable flooded vegetation for spawning purposes, spawning will not be impacted by the dam. As eel migrations could be blocked by the dam wall, either a suitable eelway should be built or preferably the design of the dam overflow should be constructed (e.g. roughened, gently-sloping spillway) so as to allow eels to use their natural ability to "climb" over the wall.

6.3.2 High Flows

There are four proposed scenarios for the size (and associated impact) of the proposed Zalu Dam above Lusikisiki town and on the Xura tributary, ranging from a smaller (Scenario 1) through to a progressively larger (Scenarios 2, 3, and 4) dam. The increased dam size will result in lower frequencies of the provision of flood EWRs, and increasing the number of consecutive years that flood EWRs will not be provided in full.

It can be seen in **Table 6.2** that the frequency of spilling months reduces by approximately 50% between ***Scenario 1*** (least developed scenario) and ***Scenario 4*** (most developed scenario). Scenarios 1, 2, 3 and 4 show that the expected frequency of the proposed Zalu Dam spilling is 45%, 34%, 30% and 23%, respectively (DWA, 2013).

The total annual **volume** specified for floods at EWR 1 according to the Preliminary Intermediate Reserve determination is 2.86 million m^3/a. A summary of the spill analyses shows that the total annual volume of spills exceeds the flood requirement of EWR, but compliance with specific monthly volumes decreases from 62% to 47%.

Table 6.2: Summary of the spill analyses (Intermediate reserve requirement of 2.9 million m^3/a)

Scenario	Average high flow EWR supplied (million m^3/a)	Number of shortages	Longest consecutive years with shortages
Scenario 1	7.19	33 (38% of the years)	5 years
Scenario 2	5.47	42 (49% of the years)	6 years
Scenario 3	5.16	43 (51% of the years)	6 years
Scenario 4	4.16	47(53% of the years)	8 years

Input on ecological impacts in terms of the drivers, i.e. geomorphology and riparian vegetation, are shown below.

a) Geomorphology

This section of the report was authored by Mark Rountree of Fluvius Consultants, who served as the **geomorphologist** for the study.

The impacts downstream are summarised into three zones (Figure 6.2):

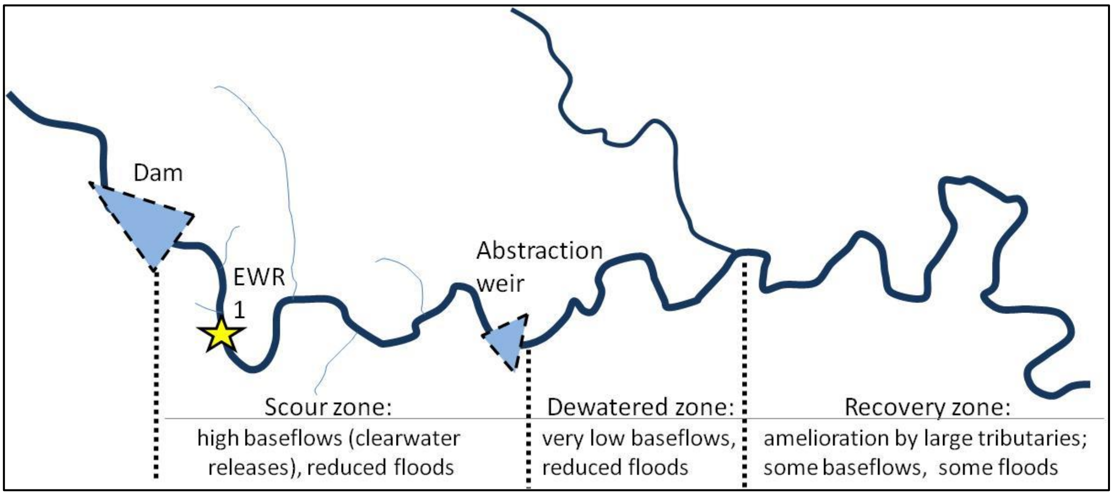

Figure 6.2: **Line diagram (not to scale) illustrating the various impact zones below the proposed dam**

- A **scour zone**, where the clear water (sediment free) released from the dam will cause increased bed and bank scour of the river channel. This impact will decrease downstream as the sediment load increases from channel erosion upstream and minor inputs from small tributaries;
- A **dewatered zone** below the abstraction weir, where baseflows will be reduced (due to the abstraction) and floods will remain reduced due to the upstream dam; and
- A **recovery zone** downstream of larger tributary junctions, where baseflows and floods will be reintroduced and the impacts of the dam significantly ameliorated.

Note that these zones are equivalent to reaches 1, 2 and 3.

Impacts in the Scour Zone (i.e. Reach 1)

The condition of the river geomorphology in the scour zone will degrade irrespective of the scenario considered, since sediment will be trapped in the dam, causing clearwater (sediment free) releases to the downstream reach. These clearwater releases will scour the bed of this reach, causing deepening of the channel in alluvial sections and widening in sections were shallow bedrock prevents incision.

Under Scenario 1, more flood releases would create increased frequent scour and sediment redistribution around the lower banks, whereas under Scenario 4, the less frequent floods would promote the development of a deeper, narrower single channel. Under all scenarios, the geomorphology would be degraded as a result of the increased erosion of the channel caused by the loss of sediment. There is little that can be done in terms of flow management to ameliorate this. The bed of the river channel is likely to become coarser and more stabilised as larger sediments and bedrock increase at the expense of gravels and fines. This will cause a degradation of the geomorphology from a current PES of an A/B to a C under all scenarios.

Impacts in the Dewatered Zone (i.e. Reach 2)

At the abstraction weir the baseflows released from the dam will be abstracted from the river. This will result in the reach immediately downstream of the weir experiencing very low baseflows. The floods (spills) from the dam, and flows from the small upstream tributaries between the dam and weir should not be greatly impacted – these should pass over the weir to the downstream reach. The effects of reduced sediment load should be ameliorated by upstream erosion and tributaries at this point, so flows can be used to manage the geomorphological condition. Scenario 1 therefore offers the best ecological option for the dewatered zone, since under this scenario spills from the (smaller) dam will be largest and most frequent. Scenario 4 provides the least ecologically desirable option for this zone of the river, since this provides the fewest and smallest spills.

Impacts in the Recovery Zone (i.e. Reach 3)

Downstream of large tributary junctions, the impacts of the dam will be progressively reduced through the amelioration provided by sediment and inflows entering from the tributaries. **As with the upstream dewatered zone though, Scenario 1 offers the most and Scenario 4 the least ecologically desirable option, since the more frequent spills would serve to mimic the natural hydrology of the system most closely.** Reduced floods are likely to cause a degradation of the riparian and in-channel habitat conditions through reduced scour abilities of the river.

b) Riparian vegetation

This section of the report was authored by Dr Brian Colloty of Scherman Colloty & Associates, who served as the vegetation specialist for the study.

As described in the section above, the proposed dam will impact not only on the river system in terms of flow modification, but also present changes to the aquatic environment with regard to habitat alteration. Habitats colonised by riparian plants will either be lost or created, depending on erosion and the later deposition of any mobilised sediment. Riparian habitat alteration can thus be directly linked to the three impact zones described in the geomorphological section, while the degree of impact would thus be associated with proposed scenarios regarding reducing the flood frequency and maintaining constant baseflows.

Impacts in the Scour Zone (i.e. Reach 1)

The sediment free or clearwater releases and the resultant scour will decrease the availability of any riparian habitat (instream and marginal), particularly where incision takes place within the alluvial sections coupled to the loss of fine sediment needed for plants to root in, i.e. the riparian zone will narrow, losing its eco-tonal or transitional nature between the aquatic and terrestrial environments.

With regard to assessing the various scenarios, all four would result in the overall reduction in width of the riparian zone, with Scenario 1 possibly creating the greatest impact due to the frequency of spills being provided in the zone.

Impacts in the Dewatered Zone (i.e. Reach 2)

The potential reduction in baseflows, due to abstraction at the weir, would impact on the potential availability of water to supply the adjacent riparian zones and could thus reduce the overall extent of these habitats. **Scenario 1 therefore presents a better option than the other scenarios for the dewatered zone, as the spills are anticipated to be larger and more frequent, thus inundating and maintaining the riparian zones.** This would also prevent the increased cover of woody vegetation, which does not naturally dominate the riparian zones.

Conversely, Scenario 4 would provide the least number of spills and riparian inundation volumes and would be the least favourable option.

Impacts in the Recovery Zone (i.e. Reach 3)

As mentioned in the Geomorphological section, several compounding factors would result in the recovery of the river system, due to flows and sediments being introduced by downstream tributaries, below the Dewatered zone. The recovery is thus linked to these introductions being made, which then return the system variability, which is an important part of maintaining diversity and function of the riparian zone. **Scenario 1 would thus be the most desirable with respect to maintaining the diversity in flows and volumes (high number of spills above the constant baseflow).** This then prevents the colonisation of these zones by woody plant/tree components, which are atypical of the natural conditions.

Conclusion: Riparian vegetation

Based on the anticipated spill frequency, Scenario 1 one would present the best opportunity as compared to the other scenarios to maintain some of the extent and diversity of the current riparian zones, while reducing unwanted woody vegetation. It is anticipated that the PES for the two lower zones would not be affected, but the PES at EWR 1 would probably change from a current C to a D rating due to riparian habitat being removed within the scour zone, as shown in the output of the Level 4 VEGRAI. Scenarios 2-4 would have the greatest impact, resulting in a reduction of the width of the riparian zone, while increasing the number of terrestrial species.

6.4 Conclusions and Recommendations

The following recommendations can be made regarding ecological requirements and dam development.

6.4.1 Demands from Lusikisiki Resulting in Releases Rower than the A/B Requirements

It is possible that during the initial years, i.e. before Lusikisiki development has reached its full potential, releases will be lower than the REC requirements (A/B) during certain months at EWR 1. In that case, the baseflow release must be 'topped-up' to match the REC requirement. As inflows to the dam are largely natural, the installation of a logger or gauge plate at a rated section somewhere suitable upstream of the dam, and that can measure low flows, would assist with dam operation and the release of EWR flows. A natural flow duration table (FDT) can be established at the rated section. Incoming flows are measured and then compared to the FDT to determine the percentile that it represents for the specific month. The same percentile is then read off the EWR 1 rule table to determine the EWR flows that should be released. This should be done at maximum twice a month and only when the dam is not spilling.

6.4.2 Monitoring

Monitoring of the system is critical. A new flow measuring point (or upgraded monitoring at downstream weir) must be instituted downstream of Zalu Dam to measure flow and EWR compliance at a high level of confidence. A real-time water quality monitoring station can also be included at this point. It is also assumed that EWR 1 will be included as a priority site in the national River Health Programme.

Note that if EWRs are not being met at EWR 1 in the future, the allocated yield must be re-allocated to meet the ecological objectives at EWR Site 1.

6.4.3 Stretch of Xura River Below Zalu Dam

It has to be acknowledged that the construction of the dam, and impacts related to the presence of the dam (barrier, disturbance to the sediment regime e.g. scouring, roads, etc.) could all impact on the PES of the downstream river; and it is unlikely that the river will maintain its A/B status. Monitoring will have to be carefully structured so that the cause of the impacts can be identified and appropriate mitigation recommended. All impacts cannot be allocated to the impact of continuous baseflows and physical impacts due to dam-building itself must be identified as such.

6.4.4 Stretch of River Immediately Below the Weir

It is acknowledged that the river immediately below the weir will have very little flows if the dam is not spilling and the whole release is being abstracted. This impact only represents a very short distance, as no impact is anticipated at the end of Reach 3. It must be noted, however, that the beginning of the reach may already be in a category lower than C PES due to the local impacts of Lusikisiki and its WTW. Managing local impacts could mitigate some of the impact of decreased flows until the first significant tributary makes its contribution.

6.4.5 Trade-offs

If Scenarios 2-4 were to be instituted, an A/B river may be degraded to at least a C category river. A trade-off may be to put a moratorium on development downstream of the Xurana River confluence and maintain the Msikaba River and its estuary in at least the present state.

7 ECOCLASSIFICATION: EWR 2 (MSIKABA RIVER)

7.1 EIS RESULTS

The EIS evaluation resulted in a **MODERATE** importance rating. The highest scoring metrics were:

- Unique (instream) species: *Barbus* sp. still being described and possibly only occurring in four Transkei rivers;
- Refugia and critical habitat (instream habitat): Important due to lack of strongly perennial tributaries;
- Migration route (instream): Important for eels at the start of system; and
- Migration corridor (riparian): Very distinct and different type of habitat present in gorge. Important for birds, and other riparian fauna.

7.2 REFERENCE CONDITIONS

The reference conditions at EWR 2 are summarised below in **Table 7.1**.

Table 7.1: EWR 2: Reference conditions

Component	Reference conditions	Conf
Hydrology	Updated simulated monthly natural flow (1920 to 2007).	2
Water Quality	No Reference Condition data was available. RC based on a river benchmark conditions as outlined in DWAF (2008b).	2
Geomorphology	Meandering pool-riffle system with large, sparsely vegetated lateral bars. Riffles of mobile cobbles with some gravels and boulders.	4
Riparian vegetation	It was understood that broad riparian zones would not be a feature of the study area due to the steep incised valleys, and when found these would be associated with scarp forest or thickets that extend down into these river valleys, while the remainder of the catchments would be dominated by grassland and emergent vegetation within the riparian zones. Very steep river banks, within incised river valley that would have been covered by thicket and forest associated species. Riparian obligates would have been limited to *Combretum* and *Ziziphus* type species, which are still found in numbers along the small tributaries associated with this EWR site. Very small or confined floodplains/terraces were found within the majority of the reach. The mobility of sediments and bars also contribute to some instability within the site, which limits the colonisation of instream vegetation in some areas of the reach. The inferred reference state was thus based on the present structure and function of the observed present day species (cover). Confidence was mostly moderate; limited by the lack of information that exists on the reference state of these systems.	2
Fish	Three fish species would be present (*B. amatolicus, A. mossambica* and *A. marmorata*). Clean, unbedded rocks in pools as well as in riffles, and deep refuge pools with little silt on substrate. The presence of catadromous fish species was possibly excluded by natural waterfall or cascade (located about 15 km downstream of EWR 2) which prevents migration from the estuary.	2

Component	Reference conditions	Conf
Inverts	The upstream DWA Msikaba sampling site referred to in **Table 1.3** (Data Availability) had a lower SASS5 score than that of EWR 2, and was thus not considered an appropriate reference site. It was used nonetheless to inform the final reference condition. Of the nearby Eastern Cape river sites reviewed, only one site, with a single sample, was considered appropriate as the major input to the reference condition, in terms of its width, position in catchment, open canopy, habitat diversity, invertebrate community, and overall SASS5 score. This was a site on the Mtamvuna River, locality: S 31° 29’ 50.6”, E 29 °31 43.2”. This site occurs in Ecoregion II 17.01 and Quaternary T40E. The score at this site was slightly better than that at EWR 2. The data was sourced from DWA: EC, and the sample date for the data was 1 Nov 2004. In the natural (reference) state slightly less disturbance and better water quality (lower fines, clearer water) was expected. Surfaces of cobbles and boulders would be clear of fines and algae.	2.5

7.3 Present Ecological State

The PES reflects the changes in terms of the EC from reference conditions. The summarised PES information is provided in **Table 7.2** and **Table 7.3** provides summarised water quality data.

Table 7.2: EWR 2: Present Ecological State

Component	PES Description	EC	Conf
Hydrology	Very little upstream catchment development with negligible impact on the volume of the flow. Abstraction to Lusikisiki in the Xura River tributary was less than 1% of the EWR 2 MAR, which is 128.9 million m^3. A very small impact on the low flow was expected at this site.	A/B	4
Water Quality	PES data was extrapolated from results of EWR 1 as there are no other water quality monitoring points in the area, and used together with land-use information. The main water quality issue was nutrient enrichment due to catchment-based activities (e.g. non-functioning WTWs around Lusikisiki), with potential toxics from Holycross Hospital located upstream.	B	2
Geomorphology	The mobile bed of the riffles was composed of cobbles, gravels and some boulders. There were large cut banks where the channel was meandering back into old terraces (6 – 8 m high). Some of this erosion may have been further exposed by the recent (2011) large floods in the area. Alien vegetation dominated the seasonal and ephemeral zones. Large lateral bars were composed of cobbles, gravels and fines, with the seasonal and ephemeral zones becoming increasingly fine.	A	4
Riparian vegetation	The present marginal zone was close to the reference state, possibly with a small loss of species cover and abundance due to trampling, grazing and alien plant cover. As a result only 5 dominant marginal species were observed. These were however typical of the region, with no rare or endemic species being observed. The species that were found have adaptive life histories, able to tolerate low to no flow conditions for short periods as well as high flow conditions. Most species require moist soils in order to survive. The marginal species found were also tolerant of the mobile species, using specialised rooting structures or selective reproductive strategies (annual, with large contributions to the local seed bank). Lower and Upper zone species were largely flow independent and only require inundation for very short periods at least once a year. The present cover and abundance was however limited by the high percentage of alien plant cover and a high degree of trampling and grazing.	C	3
Fish	The single *Barbus* species expected was found in very high abundance at the site in all suitable habitats. Slow-Deep habitats, i.e. > 1.4 m, were not sampled so it was very likely that Anguillid eels were present although none were captured. Good quality	A/B	2

Component	PES Description	EC	Conf
	habitat was present with all expected hydraulic habitats suitable for fish. Some siltation was present in deep pools and algal growth in backwaters indicated nutrient input, but had limited impact on fish.		
Inverts	The invertebrate community was slightly more impacted than that at EWR1. The PES reflected relatively low impacts to the river. The community included a number of sensitive, flow-dependent taxa scoring >10 (Perlidae, Baetidae >2 spp, Heptageniidae, and Chlorosyphidae). In the natural state, one would anticipate additional taxa of this and higher sensitivity levels, as at the upper site (e.g. Psephenidae, and Athericidae) and other similarly high-scoring taxa which occur in the Eastern Cape (e.g. Philopotamidae, Platycnemidae, and Pisuliidae). The loss of these taxa probably related largely to deterioration in water quality due to upstream inputs (Lusikisiki WTW discharge and possible Holycross Hospital effluents). Nutrient levels and EC in particular were elevated. Fines were also fairly high at this site, which compromised habitat quality.	B	3

Table 7.3: EWR 2: Present Ecological State: Water Quality

RIVER	Msikaba River	Water Quality Monitoring Points		
EWR SITE	2	**RC**	Benchmark conditions for an A category river (DWAF, 2008b)	
		PES	Extrapolated from T6H004	
Confidence assessment	Confidence in the assessment was **low** as results were extrapolated from EWR 1.			
Water Quality Constituents		**Value**	**Category (Rating) / Comment**	
Response variable	Biotic community composition: MIRAI score	83.1	B	
	Fish: FRAI score	89.6	A/B	
	Diatoms	SPI = 15.1	B (1) (n = 1)	
OVERALL SITE CATEGORISATION (based on PAI model)		**B (83.2%)**		

7.3.1 EWR 2: Trend

The trend was also assessed. Trend refers to the situation where the abiotic and biotic responses have not yet stabilised in reaction to catchment changes. The evaluation was therefore based on the existing catchment condition. The trend for all components was stable (refer to **Table 7.7**) as there had been little change from reference conditions. There were therefore limited developments in recent years to which the biological responses still had to react to.

7.3.2 EWR 2: PES Causes and Sources

The reasons for changes from the reference conditions had to be identified and understood. These are referred to as causes and sources. The PES for the components at EWR 2 as well as the causes and sources for the PES are summarised in **Table 7.4**.

Table 7.4: EWR 2: PES Causes and sources

	PES	Conf	Causes	Sources	F/NF	Conf
Hydro	A/B	4	Decrease in low flow.	Forestry (negligible). Cattle watering, alien vegetation (negligible). Abstraction from Xura River for Lusikisiki.	F	3
Water Quality	B	2.5	Nutrient levels were elevated, with orange scum present around rocks. Toxics were expected in the system, with fluctuations in temperature and oxygen.	Elevated nutrient levels were linked primarily to land use, e.g. upstream non-functioning WTWs, Holycross Hospital and cattle in the area. The hospital could also be a source of toxics.	NF	2.5
Geom	A	4	Minor increase in sediment.	Cattle/trampling and land use change.	NF	3
Riparian vegetation	C	3	Reduced plant cover due to trampling.	Cattle, goat and pedestrian access. Limited harvesting of valley thicket and upper zone vegetation also occurred.	NF	4
			Reduction in plant cover and abundance.	Alien plant growth, which out-competes the natural vegetation.		
	PES	**Conf**	**Causes**	**Sources**	**F/NF**	**Conf**
Fish	A/B	2	Some siltation in deep pools reducing substrate cover for fish.	Bank collapse and erosion due to cattle trampling and alien vegetation in riparian zone.	NF	2
			Algal growth on rocks and filamentous algae in calm areas.	Nutrients *via* domestic effluent from upstream villages and hospital (Flagstaff) and cattle droppings.		
			Marginal vegetation removal.	Cattle and goat grazing, possibly also anthropogenic removal.		
			Increased temperatures and lowered DO levels at low flows.	Reduced flows due to increased abstraction, particularly during low flow periods.	F	
			Reduced connectivity for fish and eels due to shallow depths at riffles.			
Inverts	B	3	Disturbance to lateral bar and banks.	Cattle trampling, footpaths, wood-cutting lead to low-level erosion.	NF	2
			Elevated fines (at access points only).	Access paths and roads, high clay content in this part of the catchment.		
			Increased nutrient levels.	Upstream inputs (e.g. Lusikisiki WTW), cattle and human waste.		
			Encroachment of alien vegetation on banks.	Disturbance due to trampling, and regular access by local inhabitants.		

The major issues that have caused the change from reference conditions were non-flow related (catchment activities) which included:

- Trampling and limited erosion (cattle);
- Increased nutrient levels (cattle, discharges from upstream WTWs and Holycross Hospital); and
- Alien vegetation.

7.3.3 EWR 2: PES EcoStatus

To determine the EcoStatus, the macroinvertebrates and fish component scores firstly had to be combined to determine an instream EC. The instream and riparian ECs were then integrated to determine the EcoStatus. Confidence was used to determine the weight which the EC should carry when integrated into an EcoStatus (riparian, instream and overall). The EC percentages are provided (**Table 7.5**) as well as the portion of those percentages used in calculating the EcoStatus.

Table 7.5: EWR 2: EcoStatus

INSTREAM BIOTA	Importance Score	Weight
FISH		
1. What is the natural diversity of **fish** species with different flow requirements?	2	80
2. What is the natural diversity of **fish** species with a preference for different cover types?	4	100
3. What is the natural diversity of **fish** species with a preference for different flow depth classes?	3	90
4. What is the natural diversity of **fish** species with various tolerances to modified water quality?	2	80
MACROINVERTEBRATES		
1. What is the natural diversity of **invertebrate** biotopes?	2	90
2. What is the natural diversity of **invertebrate** taxa with different velocity requirements?	3	100
3. What is the natural diversity of **invertebrate** taxa with different tolerances to modified water quality?	2	90
Fish	**89.6 (A/B)**	
Macroinvertebrates	**83.1 (B)**	
Confidence rating for instream biological information	**2.5**	
INSTREAM ECOLOGICAL CATEOGORY	**B**	
Riparian vegetation	**72.3 (C)**	
Confidence rating for riparian vegetation zone information	**3.7**	
ECOSTATUS	**B/C**	

7.4 RECOMMENDED ECOLOGICAL CATEGORY

The REC was determined based on ecological criteria only and considered the EIS, the restoration potential and attainability thereof. As the EIS was **MODERATE**, and the PES (instream) was already in a good state, no improvement was required. One might have argued that the riparian vegetation of a C EC should have been improved to a B EC; however, this improvement was based on non-flow related aspects. The REC was therefore set to maintain the PES of a B/C with specific emphasis of the B EC for instream condition.

7.5 ALTERNATIVE ECOLOGICAL CATEGORY (AEC)↓

The hypothetical scenario focused on the presence of Zalu Dam assuming no knowledge of the operation and design and that no releases for EWRs were to be made. The hypothetical conditions included the same conditions as in the Xura River as considered for the EWR 1 AEC↓, as well as further decreased baseflows in the Msikaba River and increased nutrients and electrical conductivity due to irrigation return flows. Predicted impacts on the various abiotic and biotic responders for the hypothetical scenario are described as:

- **Geomorphology:** Stabilization of lateral bars, leading to the establishment of alien vegetation, and more fines in the main channel;
- **Water quality:** Increased nutrients and salts, with shallower conditions resulting in increased temperature and oxygen fluctuations;
- **Riparian vegetation:** Increase in woody alien vegetation and marginal vegetation, unless marginal vegetation growth was limited by shading due to alien vegetation;
- **Fish:** Siltation and increasing nutrient levels would cause a reduction in habitat availability, which would result in a decrease in FROC and abundance. Shallower water causing reduced connectivity; and
- **Macroinvertebrates:** Reduced flows would result in a loss of more sensitive rheophilics at times and increase the abundance of more resilient species.

Each component was adjusted to indicate which metrics would react to the hypothetical scenario. The rule based models are available electronically and summarised in **Table 7.6**.

Table 7.6: EWR 2: AEC↓

	PES	AEC↓	Comments	Conf
Water Quality	B	C	Reduction in baseflows and floods in the Xura River tributary would result in a number of water quality changes. Associated with this was an anticipated increase in irrigation along the Msikaba River with significant irrigation return flows impacting on the system. Water quality changes would be as follows: Increased nutrient levels and salts, some increase in fines and turbidity, and fluctuations in temperature and oxygen levels due to fluctuating flows in the shallow Msikaba River system.	3
Geom	A	B	Slight reduction in floods (due to upstream dam and assumed increased abstractions) would allow more alien vegetation to establish on the lateral bars, stabilising these features. Some additional fines and embeddedness could develop within the channel.	2
Rip veg	C	C/D	Due to the possible reduction in floods, the present day alien vegetation could increase (cover) and out-compete the marginal vegetation. This would also reduce the overall marginal and instream vegetation, while increasing bank instability. Trampling and grazing would continue in the lower and upper zones, until a point where the alien vegetation completely encroach this zone. This would further reduce the cover and abundance of indigenous species.	2

	PES	AEC↓	Comments	Conf
Fish	A/B	B/C	Reduction in fish (and eel) numbers and FROC would be due to the loss of substrate cover for fish due to increased embeddedness of rocks. Increased stress due to reduced water quality (higher temperatures and lowered DO levels) and reduction in connectivity over shallow rivers due to reduced flows.	2
Inverts	B	C	The more sensitive elements of the invertebrate community would be reduced in abundance, and certain rheophiles could decline markedly in abundance or disappear altogether during the dry season (depending on the degree to which depth and flow where to be lowered). These taxa are likely to be able to breed towards wet season and could thus reappear during the wet season.	3

7.6 Summary of Ecoclassification Results

Table 7.7 summarizes the EcoStatus of EWR 2.

Table 7.7: EWR 2: Summary of EcoClassification results

Driver Components	PES & REC	Trend	AEC↓
IHI HYDROLOGY	A/B		
WATER QUALITY	B		C
GEOMORPHOLOGY	A		B
Response Components	**PES**	**Trend**	**AEC↓**
FISH	A/B	0	B/C
MACRO INVERTEBRATES	B	0	C
INSTREAM	B	0	C
RIPARIAN VEGETATION	C	0	C/D
ECOSTATUS	B/C		C
INSTREAM IHI	B		
RIPARIAN IHI	B/C		
EIS	MODERATE		

8 EWR 2 (MSIKABA RIVER): DETERMINATION OF STRESS INDICES

8.1 INDICATOR SPECIES OR GROUP

The fish and invertebrate indicator group was the same as for EWR 1 (refer to **Section 4.1**).

8.2 STRESS FLOW INDEX

A stress flow index was generated for every component (fish and macroinvertebrates) and season (wet and dry), and describes the progressive response of flow dependent biota to flow reduction. The stress flow index was generated in terms of habitat and biotic response.

The integrated stress curve represents the highest stress for either fish or macroinvertebrates at a specific flow for the wet and dry season. The species stress discharges in **Tables 8.1** and **8.2** indicate the discharge evaluated by specialists to determine the biota stress. The highest discharge representing a specific stress was used to define the integrated stress curve (**Figure 8.1**).

In **Figure 8.1** the fish stress index represents the integrated stress range 0 – 10 for the dry season, i.e. the purple curve (representing the fish stress index) is lying 'beneath' the integrated stress curve (black). For the wet season, the macroinvertebrate stress index represents the integrated stress range 1 – 4.2, therefore the red curve is lying 'beneath' the integrated stress curve (black) (**Figure 8.1** – Wet season).

The stress flow index is provided in **Figure 8.1** and **Tables 8.1** and **8.2** below.

Table 8.1: EWR 2: Dry season species stress used to determine biotic stress

Stress	Flow (m³/s)		Integrated Flow (m³/s)
	FISH	INVERTS	
0	1.27	1.27	1.27
1	1.02	0.79	1.02
2	0.8	0.63	0.8
3	0.65	0.38	0.65
4	0.51	0.26	0.51
5	0.41	0.19	0.41
6	0.33	0.13	0.33
7	0.26	0.1	0.26
8	0.19	0.06	0.19
9	0.11	0.01	0.11
10	0	0	0

DRY SEASON **WET SEASON**

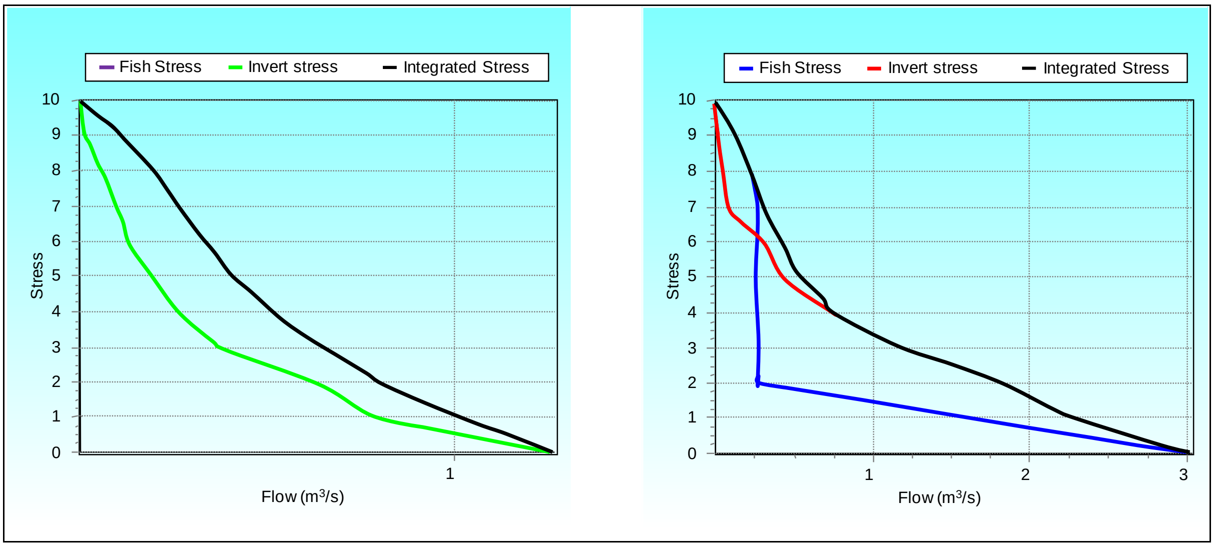

Figure 8.1: EWR 2: Species stress discharges used to determine biotic stress

Table 8.2: EWR 2: Wet season species stress discharges used to determine biotic stress

Stress	Flow (m³/s)		Integrated Flow (m³/s)
	FISH	INVERTS	
0	3.03	3.03	3.03
1	1.6	2.27	2.27
2	1.25	1.82	1.82
3	0.96	1.21	1.21
4	0.72	0.76	0.76
5	0.54	0.45	0.54
6	0.41	0.3	0.41
7	0.31	0.09	0.31
8	0.22	0.05	0.22
9	0.13	0.02	0.13
10	0	0	0

Table 8.3 and **Table 8.4** provide the summarised biotic response for the integrated stresses during the dry and wet seasons.

Table 8.3: EWR 2: Integrated stress and summarised habitat/biotic responses for the dry season

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or Biotic responses
0	1.27	Fish Inverts Maximum baseflow	**Fish:** Abundance of suitable critical habitat for semi-rheophilic sub-adult eels, *A. mossambica*, i.e. high amount of preferred FS, FI and FD habitat at these flows. Abundant cover, excellent connectivity in channel for eels and very good water quality at this flow. Maximum dry season populations of eels present throughout RU. **Inverts:** Abundant high quality critical habitat for indicator taxa (Perlidae: preference for very high flows over cobble) and several other high-scoring rheophiles. Adequate physical and hydraulic habitat heterogeneity to support a diverse community of invertebrates (ranging from resilient to very sensitive). Little MV is activated as habitat at the site, however downstream, fringing vegetation is plentiful and provides a refuge for juveniles.
1	1.02	Fish	**Fish:** Instream hydraulic habitats (FS and FI) plentiful and limited FD available for the selected flow-sensitive species, *A. mossambica.* Very similar to above, with virtually same eel population densities.
2	0.8	Fish	**Fish:** Reduced FS and FI habitats and virtually no (1%) FD habitats compared to higher flows. Moderate connectivity and water quality. Only slightly reduced population size compared to optimum. **Inverts:** Slight reduction in VFCS[1] and VFBR[2] but still plentiful critical habitat to support a moderate (B) abundance of indicator taxa.
3	0.65	Fish	
4	0.51	Fish	**Fish:** Critical FS and FI habitat sufficient to maintain flow-sensitive eels, but starting to become limiting and together with reduced connectivity causes population densities to drop to moderately below potential maximum.
5	0.41	Fish	
6	0.33	Fish	**Fish:** Critical habitat for flow-sensitive eel species reduced, and thus intraspecific competition for reduced habitat increased. Connectivity between pools not possible at some critical riffles. Reduced food availability starting to become limiting and water quality (low DO and temperatures) becoming problematic. Population numbers significantly reduced from optimum.
7	0.26	Fish	
8	0.19	Fish	**Fish:** Critical FS and FI habitat very sparse, severely limiting numbers of eels. Reduced cover and intraspecific competition high and connectivity between pools non-existent exacerbates this problem. Water quality now impacting on health of eels. Marked reduction in numbers of indicator species (eels) apparent.
9	0.11	Fish	**Fish:** No suitable fast habitats (FS and FI) in riffles, and no connectivity possible between pools. Poor water quality impacting on eels and together with intraspecific competition reduces eel numbers and distribution in RU.
10	0		**Fish:** No suitable FS habitat available for eels, and no longitudinal connectivity allowing eels to move to more suitable habitats. No flow exacerbates poor water quality resulting in increased stress, disease and mortalities in eels. Low population numbers of eels survive, reducing the FROC within the RU. **Inverts:** Surface pools only. Community limited to resilient taxa with a tolerance for moderate to poor water quality.

1: VFCS – Very fast over coarse substrate *2: VFBR – Very fast over Bedrock*

Table 8.4: EWR 2: Integrated stress and summarised habitat/biotic responses for the wet season

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or Biotic responses
0	3.03	Fish Inverts Maximum baseflow	**Inverts:** Plentiful high quality critical habitat for indicator taxa. Marginal vegetation on the lateral bar is activated as slower-flow habitat, serving as a refuge area for juveniles and inverts with a preference for cover.
1	2.3	Inverts	
2	1.8	Inverts	**Inverts:** Critical habitat 50%. This flow still supports a high abundance of indicator taxa. Depth of inundation of MV (at site) reduced and this habitat becomes less valuable as cover for developing juveniles.
3	1.2	Inverts	**Inverts:** Abundant high quality critical habitat remains for indicator taxa and several other high-scoring rheophiles. Adequate physical and hydraulic habitat heterogeneity to support a diverse community of invertebrates (ranging from resilient to very sensitive). Little MV is activated as habitat at the site, however downstream, fringing vegetation is plentiful and provides a refuge for juveniles.
4	0.76	Inverts	**Inverts:** Slight reduction in VFCS and VFBR but still plentiful critical habitat to support a moderate (B) abundance of indicator taxa**.**
5	0.54	Fish	
6	0.41	Fish	**Fish:** Limited amount of preferred riffle habitat for eels available and connectivity for all species limited, thus slightly elevated natural mortalities expected.
7	0.31	Fish	
8	0.22	Fish	**Fish:** Very limited preferred riffle habitat for eels available and connectivity very low. Water quality may become problematic in hot months due to elevated temperatures and low DO levels. Elevated mortalities expected.
9	0.13	Fish	**Fish:** Virtually no preferred riffle habitat for eels available and very limited, if any, connectivity between pools. Water quality likely problematic in hot months due to elevated temperatures and low DO levels. Significantly elevated naturally mortalities among both eels and fish expected.
10	0	Zero discharge, pools remain – no suitable habitat for most biota	**Inverts:** Limited to resilient, low scoring invertebrates.

9 EWR 2 (Msikaba River): Determination of EWR Scenarios

9.1 EcoClassification Summary of EWR 2

Table 9.1 summarizes the EcoClassification state and Recommended Ecological Category for EWR 2.

Table 9.1: Output of the EcoClassification process for EWR 2 on the Msikaba River

<table>
<tr><th colspan="5">EWR 2</th></tr>
<tr><td rowspan="13">EIS: MODERATE
Highest scoring metrics used to assess the EIS, were unique instream species, presence of critical instream refuges and important instream and riparian migration corridors.

PES: B/C
Trampling and limited erosion (cattle).
Increased nutrient levels (cattle, discharges from upstream Water Treatment Works and Holycross Hopsital).
Alien vegetation.

REC: B/C
EIS was MODERATE and the REC was therefore set to maintain the PES.

AEC: C/D
A hypothetical deteriorated situation was characterised by decreased flows and the resulting response to this situation.</td><td>Driver Components</td><td>PES & REC</td><td>Trend</td><td>AEC↓</td></tr>
<tr><td>IHI HYDROLOGY</td><td>A/B</td><td></td><td></td></tr>
<tr><td>WATER QUALITY</td><td>B</td><td></td><td>C</td></tr>
<tr><td>GEOMORPHOLOGY</td><td>A</td><td></td><td>B</td></tr>
<tr><td>Response Components</td><td>PES</td><td>Trend</td><td>AEC↓</td></tr>
<tr><td>FISH</td><td>A/B</td><td>0</td><td>B/C</td></tr>
<tr><td>MACRO INVERTEBRATES</td><td>B</td><td>0</td><td>C</td></tr>
<tr><td>INSTREAM</td><td>B</td><td>0</td><td>C</td></tr>
<tr><td>RIPARIAN VEGETATION</td><td>C</td><td>0</td><td>C/D</td></tr>
<tr><td>ECOSTATUS</td><td>B/C</td><td></td><td>C</td></tr>
<tr><td>INSTREAM IHI</td><td colspan="3">B</td></tr>
<tr><td>RIPARIAN IHI</td><td colspan="3">B/C</td></tr>
<tr><td>EIS</td><td colspan="3">MODERATE</td></tr>
</table>

9.2 Hydrological Considerations

The wettest and driest months were identified as November and August respectively. Droughts were set at 95% exceedence (flow) and 5% exceedence (stress). Maintenance flows were set at 40% exceedence (flow) and at 60% exceedence (stress).

9.3 Low Flow Requirements (in terms of stress)

The integrated stress index was used to identify required stress levels at specific durations for the wet and dry month/season.

9.3.1 Low Flow (in terms of stress) Requirements

The fish and macroinvertebrate flow requirements for different Ecological Categories (ECs) are provided in **Table 9.2** and graphically illustrated in **Figure 9.1**. The results were plotted for the wet and dry seasons on stress duration graphs and compared to the Desktop Reserve Model (DRM) low flow estimates for the same range of ECs. The stress requirements are illustrated in **Figure 9.1**.

For easier reference the range of ECs are colour coded in the following tables and figures:

PES and REC: **Purple** AEC↓: **Green**

Summarised motivations for the final requirements are provided in **Table 9.3**.

Table 9.2: EWR 2: Species and integrated stress requirements as well as the final integrated stress and flow requirement

Stress Duration	Fish Stress	Fish Flow	Invertebrate Stress	Invertebrate Flow	FINAL* (Integrated stress)	Flow requirement (m^3/s)
PES and REC (Inssream): B ECOSTATUS			FISH: A/B		MACROINVERTEBRATES: B	
DRY SEASON						
5%	4.5	0.46	3	0.38	4.5	0.46
20%	3.6	0.57	2.4	0.47	3.6	0.57
40%	3.1	0.63	1.8	0.59	3.1	0.63
WET SEASON						
5%	4.5	0.64	4.7	0.55	4.5	0.64
20%	4.1	0.7	4.2	0.7	4.1	0.7
40%	3.7	0.8	3.7	0.9	3.7	0.9
AEC↓ (Instream): C ECOSTATUS			FISH: B/C		MACROINVERTEBRATES: C	
DRY SEASON						
5%	6.4	0.3	4.1	0.26	6.4	0.3
20%	4.3	0.48	3.2	0.35	4.3	0.48
40%	3.9	0.52	2.8	0.4	3.9	0.52
WET SEASON						
5%	4.9	0.56	5.1	0.44	4.9	0.56
20%	4.7	0.6	4.7	0.55	4.7	0.6
40%	4.4	0.65	4.3	0.68	4.3	0.68

DRY SEASON (August) **WET SEASON (November)**

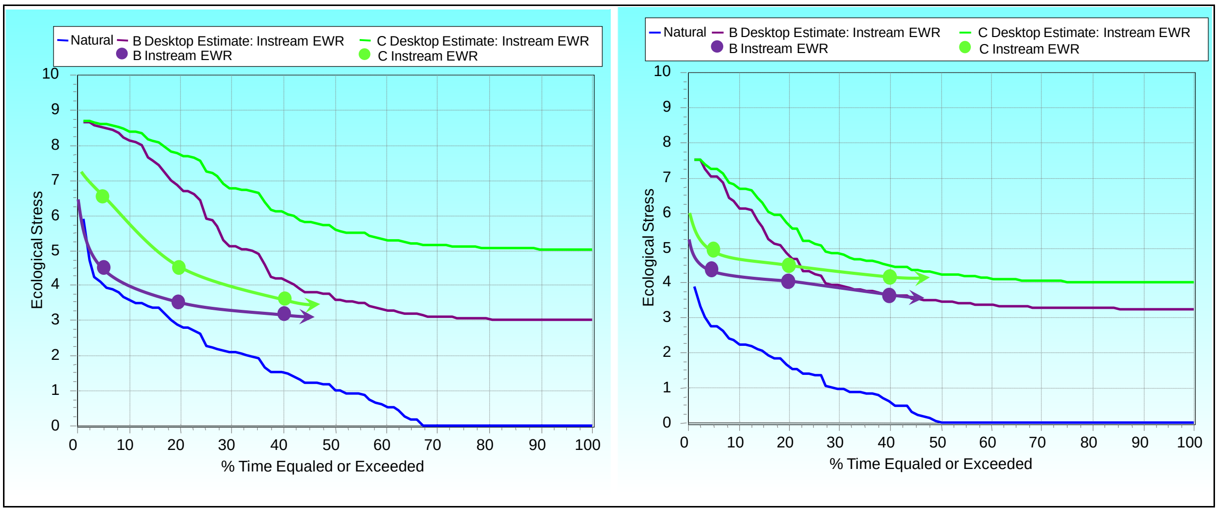

Figure 9.1: EWR 2: Stress duration curve for a PES, REC and AEC↓

Table 9.3: EWR 2: Summary of motivations

Month	% Stress duration	Component stress	Integrated stress	Flow m³/s	Comment
PES and REC (Intsream): B ECOSTATUS					**FISH: A/B MACROINVERTEBRATES: B**
Aug	5% drought	4.5 F	4.5	0.46	**Fish:** Eels – moderate amount of FS (29%) and FI (7%) and no FD habitat available in riffle – thus connectivity moderate and limited amount of preferred habitat available to sub-adult eels. Water quality may be problematic at end of the season (October) due to low flows. However, habitat conditions suitable to maintain eels in A/B category.
	20%	3.6 F	3.6	0.57	**Fish:** Slightly more FS and FI habitat present for eels and thus moderate eel passage through riffle possible in depths > 15 cm. Improved water quality compared to drought. Thus very similar populations of eels compared to drought conditions.
	40%	3.1 F	3.1	0.63	**Fish:** Slightly more FS and FI habitat present for eels and thus moderate to good eel passage through riffle possible in depths > 15 cm. Good water quality compared to lower flows. Thus slightly less stress on populations of eels compared to drought conditions
Nov	5% drought	4.5 F	4.6	0.64	**Fish:** Moderate amount of FS (32%) and FI (11%) and no FD habitat available in riffle – thus connectivity moderate and moderate amount of preferred habitat available to sub-adult eels. Water quality may be problematic due to high temperatures due to low to moderate flows. Moderate stress on eels.
	20%	4.1 + 4.2 F & I	4.3	0.7	**Inverts:** The requirement is to provide adequate (not ample) habitat for the important summer life cycle phases (breeding, egg laying, development). At this discharge, the average depth of approx. 0.15 m will ensure the surfaces of cobbles are covered and that critical flow habitat areas supply high quality habitat to rheophiles (Perlidae, Heptageniidae, Tricorythidae and Simuliidae). The limited availability of 'very fast' flow may result in reduced abundances of indicator and other sensitive taxa relative to the maintenance flow condition. There is adequate width and depth to provide a band of fringing vegetation habitat which serves as important habitat for hemipterans and certain odonates, and a refuge area for developing juveniles of some baetid species.

Month	% Stress duration	Component stress	Integrated stress	Flow m³/s	Comment
	40%	3.7 I	3.7	0.9	**Inverts:** Summer maintenance flows for a B category must satisfy the following conditions: Provide extensive, clean, very fast and fast flow (critical) habitat, inundate marginal and fringing vegetation, provide additional diverse habitat (slow flow, pools) to provide ample high quality habitat to facilitate the summer functions of hatching, breeding, egg laying, and development. The flow provided is similar to that at which the site was sampled (Sep 2010 and Feb 2011), and meets all the above criteria. For the majority of summer (60%), flows will exceed this value, which ensures that the invertebrate summer requirements are well catered for. Sensitive indicator taxa (scoring >12) and less sensitive rheophiles (scoring >10) will be present in moderate abundances at this flow.
AEC↓ (instream): C ECOSTATUS					**FISH: B/C MACROINVERTEBRATES: C**
Aug	5% drought	6.4 F	6.4	0 .3	**Fish:** Only a small amount of FS (19%) and no FI or FD habitat available in riffle – thus connectivity is low and very limited amount of preferred habitat available to sub-adult eels. Water quality may be problematic at the end of the season (October) due to low flows and high temperatures. The above conditions will result in elevated natural mortalities. Habitat suitable to maintain eels in B/C category.
	20%	4.3 F	4.3	0.48	**Fish:** Moderate amount of preferred FS (29%) and FI (7%) habitat for eels present in critical riffle, thus elevated natural mortalities as well as only limited eel movement between pools due to lack of depth.
	40%	3.9 F	3.9	0.52	**Fish:** Slightly more FS and FI habitat available for eels and improved connectivity allowing more eel movement over riffle areas compared to above.
Nov	5% drought	4.9 F	4.9	0.56	**Fish:** Moderate amount FS and FI habitats available as well as some connectivity thus allowing the eels to be maintained in a B/C category under drought low flow conditions. Water quality not expected to deteriorate to significant degrees.
	20%	4.7 F	4.7	0.6	**Fish:** Moderate amount of preferred FS (30%) and FI (10%) habitat for eels present in critical riffle, thus moderately elevated natural mortalities as well as limited eel movement between pools due to lack of depth. Probably moderate to good water quality.
	40%	4.4 & 4.3 F & I	4.4	0.68	**Fish:** Moderate amount of preferred FS (33%) and FI (13%) habitat for eels present in critical riffle, thus moderately elevated natural mortalities as well as limited impact on eel movement between pools due to lack of depth. **Inverts:** Summer maintenance flows for a C EC must perform similar functions to those requested for the B EC, however the habitat availability and quality is reduced and the fauna will be somewhat altered as a result. At this discharge only half the amount of very fast flow habitat is available (relative to the B condition), and downstream fringing vegetation is inundated to a lower height and a reduced width. The major difference between the B and C EC biota is likely to be in reduced abundances of both indicator taxa (e.g. heptageniid and perlid abundance may be reduced from a B to an A) and taxa with a preference for marginal vegetation (e.g. juvenile Baetidae, atyid shrimps, chlorolestid dragonflies, hydrophilid trichopterans and dytiscid beetles). The more sensitive elements of the taxa which occur at A abundances at higher flows (e.g.Calopterygidae) may disappear from the fauna.

9.3.2 Final Low Flow Requirements

To produce the final results, the DRM results for the specific category were modified according to specialist requirements (**Figure 9.2**). There are a range of options one can use to make these modifications, such as changing the total volume required for the year, specific monthly volumes, either drought or maintenance flow durations, seasonal distribution and changing the category rules and shape factors. The following changes were required:

PES and REC (instream): B

- Maintenance seasonal distributions set to 0.60;
- Maintenance Low Flow set to 18.37%;
- Drought seasonal distributions set to 0.40;
- Drought Low Flow set to 9.96%;
- Wet season (November) rules:
    - Low flow shape factor set to 4; and
- Dry season (August) rules:
    - Low flow shape factor set to 4
    - High flow shape factor set to 8.

AEC ↓ (instream): C

- Maintenance seasonal distributions set to 0.30;
- Maintenance Low Flow set to 13.25%;
- Drought seasonal distributions set to 0.40;
- Drought Low Flow set to 8.34%;
- Wet season (November) rules:
    - Low flow shape factor set to 4; and
- Dry season (August) rules:
    - Low flow shape factor set to 4
    - High flow shape factor set to 8.

DRY SEASON (August) **WET SEASON (November)**

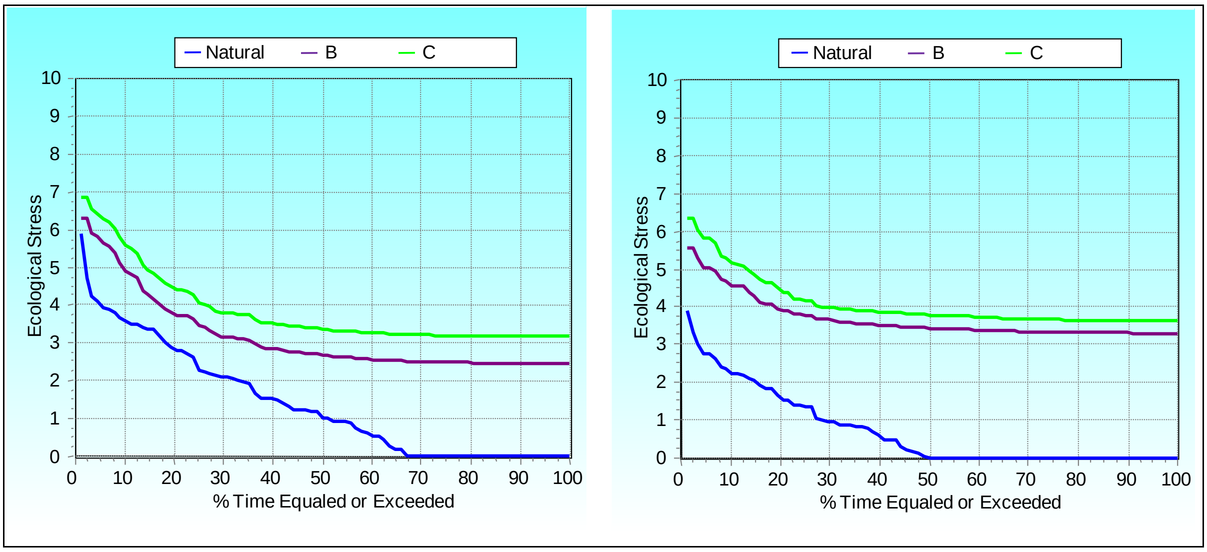

Figure 9.2: EWR 2: Final stress requirements for low flows

9.4 HIGH FLOW REQUIREMENTS

The high flow classes were identified as follows:

- The geomorphologist and riparian vegetation specialist identified the range of flood classes required and listed the functions of each flood;
- The instream specialists then indicated which of the instream flooding functions were addressed by the floods identified for geomorphology and riparian vegetation (indicated by a ✓ in **Table 9.4**); and
- Any of the floods required by the instream biota and not addressed by the floods already identified, were then described (in terms of ranges and functions) for the instream biota.

Detailed motivations are provided in **Table 9.4** and final high flow results are provided in **Table 9.5**.

Table 9.4: EWR 2: Identification of instream functions addressed by the identified floods for geomorphology and riparian vegetation

FLOOD RANGE (m^3/s) FLOOD CLASS	Geomorphology and riparian vegetation motivation	Fish flood functions						Invertebrate flood functions					
		Migration cues & spawning	Migration habitat (depth etc.)	Clean spawning substrate	Create nursery areas	Resetting water quality	Inundate vegetation for spawning	Breeding and hatching cues	Clear fines	Scour substrate	Reach or inundate specific areas	Sort substrates	Migratory cues e.g. Macrobrachium (shrimps)
10 - 15 (m^3/s)	**Geomorph:** Not Applicable. **Riparian Veg:** Maintenance of hydrophillic grasses and upper marginal zone plants, minimising the potential of the areas being colonised by woody plant growth (indigenous or alien) that requires inundation more than once a year. Height 0.76 – 90 m.	√	√	√	√	√	√	√	√	√	√		√
45 - 50 m^3/s	**Geomorph:** Inundates a high terrace, flushes fines and activates cobbles. **Riparian Veg:** Results in the reduction of the woody component, which in this case reduces the alien plant growth, while maintaining facultative sedge vegetation that requires inundation at least once a year. Height 1.38 – 1.44 m.	√	√	√	√	√	√		√	√	√	√	√
88 - 95 m^3/s	**Geomorph:** Inundates and activates the highest terrace, scours channel and activates cobbles. **Riparian Veg:** Removes woody vegetation, which reduces alien vegetation, promoting growth of facultative grasses and sedges once flows have subsided. Height 1.80 – 186 m.	√	√	√	√	√	√			√	√		

The number of high flow events required for each EC is provided in **Table 9.5**. The availability of high flows could not be verified as there was no gauge.

Table 9.5: EWR 2: The recommended number of high flow events required

PES and REC (instream): B ECOSTATUS								
FLOOD RANGE (m^3/s) FLOOD CLASS	INVERTS	FISH	VEGETATION	GEOMORPH	FINAL*	MONTHS	DAILY AVERAGE	DURATION
10 - 15	5	5:1	5	-	5	Jan, Feb, Mar, Oct, Dec	10	4
40 - 50	1:3	1:1	1:3	1:1	1:1**	Mar	30	5
88 - 95		1:5	1:5	1:5	1:5	Nov	60	5
AEC↓ (instream): C ECOSTATUS								
FLOOD RANGE (m^3/s) FLOOD CLASS	INVERTS	FISH	VEGETATION	GEOMORPH	FINAL	MONTHS	DAILY AVERAGE	DURATION
10 - 15			2	-	3	Mar, Oct, Dec	10	4
40 - 50			1:5	1:3	1:3	Mar	30	5
88 - 95			1:5	1:5	1:5	Nov	60	5

* *Final refers to the agreed on number of events considering the individual requirements for each component.*

** *Refers to frequency of occurrence, i.e. the flood will occur annually.*

9.5 FINAL FLOW REQUIREMENTS

The low and high flows were combined to produce the final flow requirements for each EC as:

- An EWR table, which shows the results for each month for high flows and low flows separately (**Tables 9.6 – 9.7**); and
- An EWR rule table which provides the recommended EWR flows as a duration table, linked to a natural trigger (natural modelled hydrology in this case). EWR rules were supplied for total flows as well as for low flows only (**Tables 9.8 – 9.9**).

The rule curve is useful for water resources modelling, whilst the EWR table provides information on the MAR at the EWR as well as the EWR required, category and rule curve definition. The information on the EWR is broken down to show the split between high and low maintenance flows, and also provide drought flows.

Table 9.6: EWR 2: EWR table for PES and REC (instream): B

Desktop version:		2	Virgin MAR (million m³)		128.945	
BFI	0.433	Distribution type			T Reg Coast	
MONTH	LOW FLOWS		HIGH FLOWS (m³/s)			
	Maintenance (m³/s)	Drought (m³/s)	Instantaneous peak	Daily average (incl. baseflow)	Daily average (excl. baseflow)	Duration (days)
OCTOBER	0.684	0.382	10 - 15	10	9.316	4
NOVEMBER	0.889	0.467	88 - 95	60	59.111	5 (1: 5)
DECEMBER	0.847	0.446	10 - 15	10	9.153	4
JANUARY	0.790	0.424	10 - 15	10	9.21	4
FEBRUARY	0.918	0.486	10 - 15	10	9.082	4
MARCH	0.914	0.459	10 - 15 40 - 50	10 30	9.086 29.086	5
APRIL	0.846	0.450				
MAY	0.691	0.385				
JUNE	0.654	0.374				
JULY	0.629	0.332				
AUGUST	0.565	0.335				
SEPTEMBER	0.601	0.353				
TOTAL million m³	23.684	12.837	16.687			
% OF VIRGIN (natural)	18.37	9.96	12.98			
Total EWR	40.372					
% of MAR	31.31					

Table 9.7: EWR 2: EWR table for AEC↓ (instream): C

Desktop version:		2		Virgin MAR (million m³)		128.945	
BFI	**0.433**	**Distribution type**				**T Reg Coast**	
MONTH	**LOW FLOWS**		**HIGH FLOWS (m³/s)**				
	Maintenance (m³/s)	**Drought (m³/s)**	**Instantaneous peak**	**Daily average (incl baseflow)**	**Daily average (excl baseflow)**	**Duration (days)**	
OCTOBER	0.510	0.317	10 - 15	10	9.49	4	
NOVEMBER	0.602	0.388	88 - 95	60	59.398	5 (1: 5)	
DECEMBER	0.577	0.371	10 - 15	10	9.423	4	
JANUARY	0.553	0.352					
FEBRUARY	0.630	0.404					
MARCH	0.604	0.392	10 - 15 40 - 50	10 30	9.396 29.396	5 (1: 3)	
APRIL	0.584	0.373					
MAY	0.513	0.320					
JUNE	0.506	0.310					
JULY	0.488	0.299					
AUGUST	0.461	0.278					
SEPTEMBER	0.484	0.293					
TOTAL million m³	17.090	10.751	9.565				
% OF VIRGIN (natural)	13.25	8.34	7.42				
Total EWR	26.656						
% of MAR	20.67						

Table 9.8: EWR 2: Assurance rules (m³/s) for PES and REC (instream): B

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.508	1.501	1.48	1.436	1.351	1.208	1.001	0.759	0.549	0.452
Nov	2.877	2.635	2.423	2.232	2.04	1.713	1.488	1.167	0.801	0.569
Dec	2.217	2.056	1.914	1.784	1.649	1.417	1.242	0.989	0.699	0.515
Jan	1.627	1.623	1.61	1.581	1.524	1.418	1.24	0.982	0.683	0.494
Feb	1.843	1.838	1.821	1.787	1.721	1.599	1.398	1.107	0.774	0.562
Mar	6.601	5.871	5.245	3.244	2.576	2.165	1.759	1.587	1.275	0.612
Apr	1.012	1.008	0.997	0.973	0.929	0.853	0.744	0.616	0.505	0.454
May	0.826	0.823	0.815	0.796	0.761	0.702	0.616	0.515	0.428	0.388
Jun	0.782	0.779	0.77	0.753	0.72	0.664	0.585	0.493	0.413	0.377
Jul	0.752	0.748	0.739	0.72	0.685	0.627	0.546	0.452	0.372	0.335
Aug	0.676	0.673	0.666	0.651	0.624	0.577	0.511	0.434	0.368	0.337
Sep	0.719	0.716	0.709	0.694	0.665	0.616	0.544	0.461	0.389	0.355

Table 9.9: EWR 2: Assurance rules (m^3/s) for AEC↓ (instream): C

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.445	1.438	1.417	1.373	1.288	1.145	0.938	0.695	0.485	0.388
Nov	2.663	2.42	2.209	2.021	1.836	1.522	1.319	1.029	0.699	0.49
Dec	2.045	1.88	1.736	1.605	1.474	1.25	1.093	0.866	0.606	0.441
Jan	0.772	0.77	0.765	0.755	0.734	0.695	0.629	0.534	0.424	0.355
Feb	0.879	0.877	0.871	0.859	0.834	0.789	0.715	0.608	0.485	0.407
Mar	3.527	3.17	2.863	2.592	2.33	1.889	1.624	1.245	0.814	0.541
Apr	0.792	0.789	0.78	0.763	0.73	0.673	0.592	0.497	0.414	0.376
May	0.695	0.693	0.685	0.67	0.64	0.589	0.516	0.431	0.357	0.322
Jun	0.686	0.683	0.675	0.659	0.628	0.577	0.504	0.419	0.346	0.312
Jul	0.661	0.658	0.65	0.634	0.604	0.554	0.484	0.403	0.333	0.301
Aug	0.625	0.622	0.615	0.6	0.572	0.524	0.457	0.379	0.311	0.28
Sep	0.656	0.653	0.646	0.631	0.602	0.554	0.483	0.4	0.329	0.295

A comparison between the Desktop Reserve Model estimates and the EWR results in terms of percentages of natural flow are provided in **Table 9.10**.

Table 9.10: EWR 2: Modifications made to the DRM (%)

Changes	PES and REC (instream): B EC		AEC↓ (instream): C EC	
	DRM	EWR	DRM	EWR
ML EWR - Maintenance low flow	18.57	18.37	10.75	13.25
DL EWR - Drought low flow	5.04	9.96	5.04	8.34
MH EWR - Maintenance high flow	12.64	12.98	10.20	7.42
Long-term % of virgin (natural) MAR	29.07	30.08	21.92	22.88

10 CONCLUSIONS

10.1 ECOCLASSIFICATION

The EcoClassification results are summarised below in **Table 10.1**.

Table 10.1: EcoClassification Results summary

EWR 1

EIS: MODERATE
Highest scoring metrics used to assess the EIS, were unique instream species, diversity of instream and riparian habitat types, presence of critical instream refuges and important riparian migration corridors.

PES: B
Trampling and limited erosion (cattle).
Increased nutrient levels (cattle, human waste and clothes washing).
Alien vegetation.

REC: B
EIS was MODERATE and the REC was therefore to maintain the PES.

AEC: C
A hypothetical deteriorated situation was characterised by decreased flows and the resulting responses to this situation.

Driver Components	PES & REC	Trend	AEC ↓
IHI HYDROLOGY	A/B		
WATER QUALITY	A/B		B/C
GEOMORPHOLOGY	A/B		C
Response Components	**PES**	**Trend**	**AEC↑**
FISH	A/B	0	B/C
MACRO INVERTEBRATES	A/B	0	B/C
INSTREAM	A/B	0	B/C
RIPARIAN VEGETATION	B/C	0	C
ECOSTATUS	B		C
INSTREAM IHI	A/B		
RIPARIAN IHI	B		
EIS	MODERATE		

(table continued on next page)

EWR 2

EIS: MODERATE
Highest scoring metrics used to assess the EIS, were unique instream species, presence of critical instream refuges and important instream and riparian migration corridors.

PES: B/C
Trampling and limited erosion (cattle).
Increased nutrient levels (cattle, discharges from upstream Water Treatment Works and Holycross Hospital).
Alien vegetation.

REC: B/C
EIS was MODERATE and the REC was therefore set to maintain the PES.

AEC: C/D
A hypothetical deteriorated situation was characterised by decreased flows and the resulting response to this situation.

Driver Components	PES & REC	Trend	AEC↓
IHI HYDROLOGY	A/B		
WATER QUALITY	B		C
GEOMORPHOLOGY	A		B
Response Components	**PES**	**Trend**	**AEC↓**
FISH	A/B	0	B/C
MACRO INVERTEBRATES	B	0	C
INSTREAM	B	0	C
RIPARIAN VEGETATION	C	0	C/D
ECOSTATUS	B/C		C
INSTREAM IHI	B		
RIPARIAN IHI	B/C		
EIS	MODERATE		

10.1.1 Confidence in Results

The confidence in the EcoClassification process is provided below and was largely based on the following:

- Data availability: Evaluation based on the adequacy of any available data for interpretation of the Ecological Category and AEC; and
- Process: Evaluation based on the confidence in the outcome and probable accuracy in defining the Present Ecological State.

The confidence score is based on a scale of 0 – 5 and colour coded where:

0 – 1.9: Low 2 – 3.4: Moderate 3.5 – 5: High

These confidence ratings are applicable to all scoring provided in this chapter. Results for EcoClassification are shown in **Table 10.2**.

Table 10.2: Confidence in EcoClassification

EFR site	Data availability									EcoClassification								
	Hydrology	Water Quality	Geomorph	IHI	Fish	Macro-invertebrates	Vegetation	Average	Median	Hydrology	Water Quality	Geomorp	IHI	Fish	Macro-invertebrates	Vegetation	Average	Median
EWR 1 (Xura)	3	3	2	3.1	3	2.5	3	**2.8**	**3**	4	4	4	3.1	4	3	3	**3.6**	**4.0**
EWR 2 (Msikaba)	2	2.5	3	3.5	2	3	2	**2.6**	**2.5**	4	3	4	3.5	2	3	3	**3.2**	**3.0**

10.1.2 Conclusions

The confidence in the EcoClassification results was Moderate to High. The higher confidence at EWR 1 was related to the presence of the gauging weir with some daily flow data (14 years) and the availability of water quality data.

10.2 Ecological Water Requirements

10.2.1 Summary of Final Results

The natural MARs as provided by AECOM are given in **Table 10.3**. The final flow requirements are expressed as a percentage of the natural MAR in **Table 10.4**.

Table 10.3: Natural and Present Day MARs of the EWR sites

Site	Natural MAR (million m³)	Present MAR (million m³)
EWR 1 (Xura)	14.17	13.4
EWR 2 (Msikaba)	128.94	126.70

Table 10.4: Summary of results as a percentage of the natural MAR

EWR site	EC	Maintenance low flows		Drought low flows		High flows		Long term mean	
		%nMAR	million m³	%nMAR	million m³	%nMAR	million m³	% nMAR	million m³
EWR 1	PES: AB	22.49	3.186	5.70	0.807	20.21	2.863	36.79	5.212
	AEC: BC	16.19	2.294	4.75	0.673	14.19	2.009	28.71	4.067
EWR 2	PES: B	18.37	23.684	9.96	12.837	12.98	16.687	30.08	38.792
	AEC: C	13.25	17.09	8.34	10.751	7.42	9.565	22.88	29.457

10.2.2 Confidence

a) Confidence in low flows

The question the confidence assessment should answer is the following:

- *'How confident are you that the low flow (with the associated high flows) recommended will achieve the EC?'*

To determine the confidence, one should consider:

- The availability and quality of data; and
- Whether the final calculated ecological water requirement represents the critical requirement. For example, if the macroinvertebrate stress requirement of a 4 at 30% was the final recommendation, and the fish stress requirement was 7 at 30%, then there should be a very high confidence that the recommended flow will achieve the EC for macroinvertebrates. In this case, macroinvertebrates will receive more flow than required, so even if the invertebrate data availability and understanding of habitat requirements are of low confidence, the confidence that the much higher flow, recommended based on fish flow requirements, will cater for invertebrate requirements and therefore should result in a high confidence that the EC will be maintained/achieved.

The low flow confidence evaluation was representative of the component (fish or macroinvertebrates) confidence which drove the flow requirement. If both components drove the flow requirement, then an average of the confidence rating is provided.

Table 10.5 provides the confidence in the low flow requirements of the biotic components (fish, macroinvertebrates). The columns shaded in green indicate which of these components dictated the final requirements. The final confidence is representative of these requirements. The confidence score is based on a scale of 0 – 5 and colour coded with 0 indicating a low, and 5 a high confidence.

Table 10.5: Low flow confidence ratings for biotic responses

EWR site	Fish	Inverts	COMMENT	Overall Confidence
EWR 1 (Xura)	3	3	**Fish:** These flows should be adequate to attain the specific EC for fish, as the preferred habitats in fast flowing water which are required by the sub-adult eels used as the indicator guild (semi-rheophilic), are present and were considered adequate in determining the stress index. In addition, these eels are capable of living in sub-optimum slow- flowing habitats for short periods, ensuring the PES will be maintained at the requested flows. However, the confidence in non-flow related impacts such as water quality issues (low DO and elevated temperatures) at low flows is low. **Inverts:** Moderate confidence that the flows requested will maintain the invertebrate PES. This confidence is based on the two site visits at a flow of approximately 0.14 m^3/s, which provided a reasonably good understanding of the cross section; and observations of flow depth and marginal vegetation (MV) inundation.	**3**
EWR 2 (Msikaba)	3	3	**Fish:** Knowledge of the flows and related fast flowing habitats which are required by the sub-adult eels used as the indicator guild (semi-rheophilic), clearly indicate that these flows should be adequate to attain the specific EC for fish. The preferred habitats in fast flowing water are present and were considered adequate in determining the stress index. In addition, these eels are capable of living in sub-optimum slow- flowing habitats for short periods, ensuring the PES will be maintained at the requested flows. However, the confidence in non-flow related impacts such as water quality issues (low DO and elevated temperatures) at low flows is low. **Inverts:** Moderate confidence that the flows requested will maintain the invertebrate PES, assuming high flows are delivered. This is based on two field visits and a good understanding of the site habitat and the ecohydraulics data.	**3**

b) Confidence in high flows

The question the confidence assessment should answer is the following:

- *'How confident are you that the high flow (with the associated low flows) recommended will achieve the EC?'*

To determine the confidence, one should consider:

- The availability and quality of data; and
- Whether the requirement requested for geomorphology was increased to also cater for riparian vegetation requirements. The riparian vegetation confidence would then be high as more water is provided.

The high flow confidence (**Table 10.6**) represents an average of the riparian vegetation and geomorphology confidence as these two components determine the flood requirements. The column shaded in green therefore again indicates which of the components dictated the final requirements.

Table 10.6: Confidence in recommended high flows

<table>
<tr><th>EWR site</th><th>Fish</th><th>Inverts</th><th>Riparian vegetation</th><th>Geomorphology</th><th>COMMENT</th><th>Overall confidence</th></tr>
<tr><td rowspan="4">EWR 1 (Xura)</td><td rowspan="4">4</td><td rowspan="4">4</td><td rowspan="4">3.5</td><td rowspan="4">3.5</td><td>Fish: The recommended frequency and magnitude of the floods will more than adequately cater for the all the migratory requirements of the catchment-wide migrations of the catadromous eel species as well as providing optimum habitats and flows for the spawning and larval rearing requirements of the small Barbus species.</td><td rowspan="4">3.5</td></tr>
<tr><td>Inverts: The floods are more than adequate for invertebrate requirements.</td></tr>
<tr><td>Riparian vegetation: The overall diversity of indigenous riparian obligate plants is very low, which is coupled to a lack of riparian habitat diversity, a result of the channel structure. Therefore the flooding requirements requested, would thus easily attain the water levels needed to sustain the various riparian zone components.

The confidence is however only moderate, due to a lack of understanding on the actual response of the alien woody vegetation to these floods. A number of additional impacts and processes are also operating within the riparian zone, but these are non-flow dependent.</td></tr>
<tr><td>Geomorphology: Sediment transport modelling and the morphological cues both identified the same flood magnitudes. Confidence in the results is relatively high, but is constrained by the short flow gauge record at the site since this has limited the understanding and analysis of sediment transport patterns over the long term.</td></tr>
<tr><td rowspan="4">EWR 2 (Msikaba)</td><td rowspan="4">4</td><td rowspan="4">4</td><td rowspan="4">3</td><td rowspan="4">1.5</td><td>Fish: The recommended frequency and magnitude of the floods will more than adequately cater for the all the migratory requirements of the catchment-wide migrations of the catadromous eel species as well as providing optimum habitats and flows for the spawning and larval rearing requirements of the small Barbus species.</td><td rowspan="4">2.25</td></tr>
<tr><td>Inverts: The floods are more than adequate for invertebrate requirements.</td></tr>
<tr><td>Riparian vegetation: The structure and complexity of this site, although wider, also exhibited a low diversity of indigenous riparian obligate plants. This is as a result of the channel structure and the dynamic state of the bars within the study reach.

Therefore the flooding requirements requested, would thus easily attain the water levels needed to sustain the various riparian zone components. The confidence is however only moderate, due to a lack of understanding on the actual response of the alien woody vegetation to these floods. A number of additional impacts and processes are also operating within the riparian zone, but these are non-flow dependent.</td></tr>
<tr><td>Geomorphology: There is no flow gauge for the site, so no sediment transport modelling could be undertaken. Confidence in the results is therefore low as the determination of flood requirement since was based on weak morphological cues at the site.</td></tr>
</table>

c) Confidence in hydrology

Note: If natural hydrology was used to guide requirements, then that confidence will carry a higher weight than normal. Hydrology confidence is provided from the perspective of its usefulness to the EWR assessment. This will be different to the confidence in the hydrology for water resources management and planning. The scale of requirements is very different, and therefore high confidence hydrology for water resource management purposes often does not provide sufficient confidence for EWR assessment. The confidence in hydrology is provided in **Table 10.7**.

Table 10.7: Confidence in hydrology

EWR site	Natural hydrology	Present hydrology	Observed hydrology	Local knowledge/information	Comment	Confidence: Median	Confidence: Average
1	3	4	3	1	The availability of an observed gauge at the site with a short data record, results in relatively moderate to high confidence.	3	2.75
2	3	3	0	1	The lack of gauge results in a lower confidence than for EWR 1.	2.75	1.75

d) Overall confidence in EWR results

The overall confidence in the results are linked to the confidence in the hydrology and hydraulics as the hydrology provides the check and balance of the results and the hydraulics converts the requirements in terms of hydraulic parameters to flow. Therefore, the following rationale was applied when determining the overall confidence:

- If the hydraulics confidence was lower than the biological responses column, the hydraulics confidence determined the overall confidence. Hydrology confidence was also considered, especially if used to guide the requirements; and
- If the biological confidence was lower than the hydraulics confidence, the biological confidence determined the overall confidence. Hydrology confidence was also considered. If hydrology was used to guide requirements, this confidence would be overriding in determining the overall confidence.

The overall confidence in the EWR results is provided in **Table 10.8**.

Table 10.8: Overall Confidence in EWR results

Site	Hydrology	Biological responses: Low flows	Hydraulic: Low Flows	OVERALL: LOW FLOWS	COMMENT	Biophysical responses: High flows	Hydraulics: High Flows	OVERALL: HIGH FLOWS	COMMENT
EWR 1	2.8	3	3	**3**	The drought flows were of moderate confidence as the EWRs were lower than the measured flow and the site was complex. There were uncertainties with the flow class modelling. The maintenance flows were rated as a 5 confidence as the range of EWRs were close to the flows requested.	3.5	2	**2**	Flows were above measured flow range. High flow strand data, but above rating for local gauge.
EWR 2	1.8	3.5	3	**3**	Flows were below the minimum measured.	2.25	2	**2**	Above measured flow range. Uncertainty in high flow slopes (non-uniform flows due to upstream/downstream pools).

11 RECOMMENDATIONS / MONITORING REQUIREMENTS

11.1 RECOMMENDATIONS

Recommendations are briefly outlined below.

EWR 1: Improvement in the confidence of the biotic components can be achieved through sampling at a wider range of river flows than were possible during this Study. These flows should ideally include lower flows than those measured. Sampling in September 2011 and February 2012 respectively was conducted at flows of:

- EWR 1: 0.16 and 0.12 m^3/s
- EWR 2: 1.2 and 1.3 m^3/s

Flow monitoring could form part of an Integrated Water Resources Monitoring (IWRM) programme. An improvement in hydraulic confidence could be achieved by obtaining a calibration in the region of the recommended drought flows and during a flood.

EWR 2: The lack of flow variability measured during the *Intermediate Preliminary Reserve Study* was similar to that experienced at EWR 1 and future monitoring should aim to improve low flow confidences. It is strongly recommended that an Ecological Water Resources Monitoring (EWRM) programme is initiated as soon as possible. The information gathered during this study is suitable for determining baseline conditions, but if too much time lapses (>5 years) between the collected baseline data and the implementation of monitoring, and significant changes have happened in the catchment, new surveys will have to be undertaken to re-set the baseline.

11.2 MONITORING

Monitoring criteria are presented in the form of Ecological Specifications (EcoSpecs) and Thresholds of Probable Concern (TPCs) per component. Ecological specifications are clear and measurable specifications of ecological attributes that define a specific EWR category. The main EcoSpecs are the RECs for each of the components, as described in **Table 3.7** and **Table 7.7** for EWR 1 and 2 respectively.

TPCs are defined as measurable end points related to specific abiotic or biotic indicators that if reached **prompt management action**. In essence, TPCs should be defined such that they provide early warning signals of potential non-compliance to ecological specifications. This concept implies that the indicators (or monitoring activities) selected as part of a long-term monitoring programme need to include biotic and abiotic components that are particularly sensitive to ecological changes associated with changes in river inflow (quantity and quality) into the system. The baseline studies that were carried out for the Preliminary Reserve determination may be considered as the baseline data against which the long-term monitoring should be carried out. Note that a specialist should be consulted when a monitoring programme is designed for the area.

11.2.1 EWR 1 (Xura River): Ecospecs and TPCs

The EcoSpecs and TPCs derived from all available data and refined from the Ecological Reserve study are provided below.

a) Hydrology

The output from the Desktop Reserve Model (DRM) – **Table 5.6** – serves as the EcoSpecs for EWR 1.

b) Water quality

EcoSpecs and TPCs are shown in **Table 11.1** and **Table 11.2** respectively and are linked to the present state water quality state as shown in **Table 3.3** and the integrated water quality category as produced by the PAI model.

Table 11.1: Water Quality EcoSpecs for EWR 1 (Xura River)

River: Xura		EWR: 1	Monitoring site: T6H004Q01
Water quality metrics		ECOSPEC	
Inorganic salts*	$MgSO_4$	The 95th percentile of the data must be ≤ 16 mg/L.	
	Na_2SO_4	The 95th percentile of the data must be ≤ 20 mg/L.	
	$MgCl_2$	The 95th percentile of the data must be ≤ 15 mg/L.	
	$CaCl_2$	The 95th percentile of the data must be ≤ 21 mg/L.	
	NaCl	The 95th percentile of the data must be ≤ 45 mg/L.	
	$CaSO_4$	The 95th percentile of the data must be ≤ 351 mg/L.	
Physical variables	Electrical conductivity	The 95th percentile of the data must be ≤ 42.5 mS/m.	
	pH	The 5th and 95th percentiles of the data must range from 4.5 to 8.0.	
	Temperature	Natural temperature range.	
	Dissolved oxygen	The 5th percentile of the data must be ≥ 8.0 mg/L.	
	Turbidity	Vary by a small amount from the natural turbidity range; minor silting of instream habitats acceptable.	

River: Xura		EWR: 1	Monitoring site: T6H004Q01
Water quality metrics		**ECOSPEC**	
Nutrients	TIN	The 50th percentile of the data must be ≤ 1.0 mg/L.	
	PO_4-P	The 50th percentile of the data must be ≤0.025 mg/L.	
Toxics		The 95th percentile of the data must be within the Target Water Quality Range (TWQR) as stated in DWAF (1996).	

** To be generated using TEACHA when the TPC for Electrical Conductivity is exceeded or salt pollution expected.*

Table 11.2: Water Quality TPCs for EWR 1 (Xura River)

River: Xura		EWR: 1	Monitoring site: T6H004Q01
Water quality metrics		**TPC**	
Inorganic salts*	$MgSO_4$	The 95th percentile of the data must be 13 – 16 mg/L.	
	Na_2SO_4	The 95th percentile of the data must be 16 – 20 mg/L.	
	$MgCl_2$	The 95th percentile of the data must be 12 – 15 mg/L.	
	$CaCl_2$	The 95th percentile of the data must be 17 – 21 mg/L.	
	NaCl	The 95th percentile of the data must be 36 – 45 mg/L.	
	$CaSO_4$	The 95th percentile of the data must be 280 – 351 mg/L.	
Physical variables	Electrical conductivity	The 95th percentile of the data must be 34 – 42.5 mS/m.	
	pH	The 5th and 95th percentiles of the data must be <4.7 and >7.8.	
	Temperature	Small deviation (less that 2°C) from the natural temperature range.	
	Dissolved oxygen	The 5th percentile of the data must be 8.2 – 8.0 mg/L.	
	Turbidity	Moderate changes to the catchment land-use resulting in temporary short term unnaturally high sediment loads and high turbidities.	
Nutrients	TIN	The 50th percentile of the data must be 0.8 – 1.0 mg/L.	
	PO_4-P	The 50th percentile of the data must be 0.02 – 0.025 mg/L.	
Toxics		The 95th percentile of the data must be within the Target Water Quality Range (TWQR) as stated in DWAF (1996).	

** To be generated using TEACHA when the TPC for Electrical Conductivity is exceeded or salt pollution expected.*

Monitoring should strive to include the following parameters:

- Temperature, dissolved oxygen (DO), turbidity/clarity – little data exists for these parameters;
- Nutrients, i.e. ortho-phosphate and Total Inorganic Nitrogen (TIN). Note that the present state concentration of TIN is already within the TPC for the category. Levels should be monitored carefully;
- Diatoms, as they have proved to be a useful indicator of water quality; and
- Note that EcoSpecs and TPCs for DO, temperature and turbidity may need revising once Zalu Dam is in place.

c) *Geomorphology*

EcoSpecs and TPCs are not provided due to the long-term changes that will be caused at the site due to dam building. The geomorphological baseline will probably need to be set again once instream monitoring commences.

d) *Riparian vegetation*

This section includes background to setting EcoSpecs and TPCs for riparian vegetation, and was authored by Dr Brian Colloty of Scherman Colloty & Associates, who served as the vegetation specialist for the study.

Introduction

The EcoSpec and TPC derivation for both EWR sites are based on methods utilised by James Mackenzie as part of the *ORASECOM Study* along the Orange River (Louw and Koekemoer, 2010). This method was found suitable for the Lusikisiki study, with limited adaptation being needed.

Method

To describe the overall state of any riparian zone the following components need to be assessed, while being compared to the Reference Conditions:

- Extent of exotic invasion;
- Terrestrial plant invasion (“Terrestrialisation”)[4];
- General vegetation structure measured using the proportion of riparian woody species;
- Reeds cover; and
- Non-woody species (grasses, sedges and dicotyledonous forbs) cover.

Note that EcoSpecs (and hence TPCs) are based on hypotheses which are still being refined. All components are estimated aerial cover (%) as this facilitates ease and speed of assessments (Louw and Koekemoer, 2010).

[4] *Terrestrialisation: the drying out of floodplain areas and wetlands which then take on terrestrial characteristics and are invaded by plants.*

Exotic invasion

Ecological specifications were set for the proportion of exotic species invading the riparian zone (**Table 11.3**). Values of perennial exotic species aerial cover (%) in **Table 11.3** were used to assess all sites within the study area – little variation between sites occurred with regard to reference percentage cover and results are thus transferable across the two sites. i.e. both sites have limited areas for the development of broad riparian zones.

Table 11.3: EcoSpecs for exotic perennial species occurrence in the riparian zone is based

Ecological Category	% Aerial Cover (Perennial Exotics)
A	0
A/B	1 - 5
B	5 - 10
B/C	10 - 15
C	15 - 20
C/D	20 - 30
D	30 - 50
D/E	50 - 60
E	60 - 70
E/F	70 - 80
F	> 80

Terrestrialisation

The occurrence of terrestrial species in the riparian zone is based on the phenomenon that terrestrial species occur naturally in the riparian zone (to greater or lesser degrees depending on vegetation biomes), but are reduced in cover and abundance by increased flooding disturbance (Louw and Koekemoer, 2010). **Table 11.4** outlines EcoSpecs for the occurrence of terrestrial woody species in the riparian zone, and excludes the presence of alien tree species in the rating.

Table 11.4: EcoSpecs concerning terrestrialisation of the three riparian zones

Ecological Category	Marginal Zone (% aerial cover)	Lower Zone (% aerial cover)	Upper Zone (% aerial cover)
A	0	0	0 - 5
A/B	0	0	5 - 10
B	0	0	10 - 15
B/C	0	1 - 5	15 - 20
C	0	5 - 10	20 - 30
C/D	0	10 - 15	30 - 40
D	1 - 5	15 - 20	40 - 50
D/E	5 - 10	20 - 30	50 - 60
E	10 - 15	30 - 40	60 - 70
E/F	15 - 20	40 – 50	70 - 80
F	> 20	> 50	> 80

Indigenous riparian woody cover

The proportion of woody riparian species in the riparian zone is not as easily transferrable to different sites and rivers as is exotic and terrestrial vegetation (Louw and Koekemoer, 2010). This is due to the continuous dynamic between the potential increase in woody cover with diminishing non-woody cover (including reeds), which is then "reset" by large flood events. "Reset" refers to the removal of woody plants by floods, with the resulting open space being available for quick colonising by non-woody species (including reeds). The rating for this unit thus assumes that if woody cover increases beyond a given value and remains high, then the flooding regime has been changed so that large floods are smaller or less frequent. When flooding frequency and disturbance decreases up the bank, the expected cover of riparian woody species will increase. **Table 11.5** outlines a basic expected pattern of riparian woody cover, but is general in nature and has been changed slightly where necessary to more realistically reflect site characteristics when setting EcoSpecs and TPCs for each site.

Table 11.5: EcoSpecs concerning indigenous riparian woody cover (% aerial cover) for sites in the Grassland Biome (EWR 1)

Ecological Category	Marginal Zone (% aerial cover)	Lower Zone (% aerial cover)	Upper Zone (% aerial cover)
A	0-2	0-2	0-2
A/B			
B	2.5	2.5	2.5
B/C			
C	5-10	5-10	5-10
C/D	10-15	10-15	10-15
D	>15	>15	>15
D/E			
E	>30	>30	>30
E/F			
F	>60	>60	>60

***Phragmites* (Reeds) cover**

This rating is based on the expectation that reeds are a common component of marginal and lower zone vegetation (**Table 11.6**); however, if a sudden increase in aerial cover is seen away from the reference state then it is assumed that an increase in alluvial deposits has occurred coupled to possible hydrological changes. This assumes that reeds will colonise open alluvium (similar to the pioneer species concept) created by floods, and will increase in cover until slowly replaced by woody vegetation as shading occurs. A natural flow regime will create a patch mosaic of woody vs. reed areas, thus a mix is always expected (in the absence of very infrequent extreme events): an increase in reed cover beyond a specified value is seen to be a loss of riverine diversity and as such will begin to reduce the EC. For sites that occur in the Grassland Biome (such as EWR 1), reeds are frequently not expected, even though they may be found (Louw and Koekemoer, 2010).

Table 11.6: EcoSpecs concerning Phragmites (Reed) cover (% aerial cover)

Ecological Category	Marginal Zone (% aerial cover)	Lower Zone (% aerial cover)	Upper Zone (% aerial cover)
A	0-2	0-2	0-2
A/B			
B	2.5	2.5	2.5
B/C			
C	5-10	5-10	5-10
C/D	10-15	10-15	10-15
D	>15	>15	>15
D/E			
E	>30	>30	>30
E/F			
F	>60	>60	>60

Results: EcoSpecs and TPCs

EcoSpecs and TPCs for **EWR 1** are shown in **Table 11.8** and **Table 11.7** provides descriptions related to the results.

Table 11.7: EcoSpec and TPC descriptions relating to riparian vegetation EWR 1

PES	Assessed Component	Zone Assessed	EcoSpec (for PES)	TPC (for PES)	Baseline (measured value,% cover) / Note
C	Exotic Invasion (perennial exotics)	Riparian zone	Maintain exotic species cover between 2 - 10%	An increase in exotic species cover above 20-30%	VEGRAI recorded 2% cover (marginal zone), 10% cover (lower zone), 5% cover (upper zone)
	Terrestrialisation	Marginal Zone	Maintain an absence of terrestrial species	An occurrence of terrestrial species	0
		Lower Zone	Maintain cover of terrestrial species at 5% or less	An increase above 5% of terrestrial species cover	5% cover
		Upper Zone	Maintain terrestrial species cover between 15 and 20%	An increase above 20% of terrestrial species cover	10% cover
	Indigenous Riparian Woody Cover	Marginal Zone	Maintain riparian woody species cover between 0 and 2%	An increase above 2% cover, OR a decrease below 0% cover	2% cover
		Lower Zone	Maintain riparian woody species cover between 0 and 2%	An increase above 2% cover, OR a decrease below 0% cover	2% cover
		Upper Zone	Maintain riparian woody species cover between 5 and 10%	An increase above 10% cover, OR a decrease below 5% cover	5% cover: Naturally a grassland vegetation type and woody species would be limited on the left hand bank

PES	Assessed Component	Zone Assessed	EcoSpec (for PES)	TPC (for PES)	Baseline (measured value,% cover) / Note
	Phragmites australis (reed) cover	Marginal Zone	Maintain reed cover <5%	An increase in reed cover above 20%	2% cover
		Lower Zone	Maintain reed cover between <5%	An increase in reed cover above 20%	2% cover

Table 11.8: EcoSpecs and TPCs relating to riparian vegetation for EWR 1

Colour coding in the table below refers to:

EcoSpec	TPC	Baseline (measured)	PES C

Ecological Category	Perennial Exotics (% aerial cover)	Reeds (% aerial cover)	Riparian Woody (% aerial cover)	Terrestrialisation (% aerial cover)
Marginal Zone				
A	0	0-2	0-2	0
A/B	1-5			0
B	5-10	3-5	2-5	0
B/C	10-15			0
C	15-20	5-10	5-10	0
C/D	20-30	>10	10-15	0
D	30-50		>15	1-5
D/E	50-60			5-10
E	60-70			10-15
E/F	70-80			15-20
F	>80			>20
Lower Zone				
A	0	0-2	0-2	0
A/B	1-5			0
B	5-10	3-5	2-5	0
B/C	10-15			1-2
C	15-20	5-10	5-10	2-5
C/D	20-30	>10	10-15	5-15
D	30-50		>15	15-20
D/E	50-60			20-30
E	60-70			30-40
E/F	70-80			40-50
F	>80			>50
Upper Zone				
A	0		2-5	0-5
A/B	1-5		5-10	5-10
B	5-10		10-15	10-15
B/C	10-15		15-20	15-20
C	15-20		20-30	20-30
C/D	20-30		>30	30-40
D	30-50			40-50
D/E	50-60			50-60
E	60-70			60-70
E/F	70-80			70-80
F	>80			>80

e) Fish

This section of the report was authored by Dr Anton Bok of Anton Bok Aquatic Consultants, who served as the fish specialist for the study. Monitoring recommendations are included as well as EcoSpecs and TPCs due to the ecological importance of the site.

Background

Note that the ecological importance of this reach of the Xura River is regarded as High due to the presence of a new un-described species of small *Barbus* (*Barbus* "Transkei" n. sp.). This new species appears genetically closer to *Barbus amatolicus* (BAMA*),* but appears more closely aligned to *Barbus anoplus* (BANO) in terms of the indicator values for the different habitat variables and tolerance ratings. For convenience and to utilize the more extensive information on the habitat preferences and tolerances of *Barbus anoplus,* this Transkei barb was thus listed as BANO in terms of this report.

This new un-described *Barbus* species (*Barbus* "Transkei" n. sp.) appears to be confined to a small number of rivers (possibly only the Msikaba and Mzintlava river systems) in Transkei (Luis da Costa, pers. comm. 21 October 2011) and is thus considered of Special Importance. Fish monitoring requirements are therefore indicated in **Table 11.9**.

Table 11.9: A summary of the fish monitoring requirements for EWR 1 (Xura River)

Fish monitoring requirements:	
Frequency:	At least every 2 years. This is due to the short life cycle of *Barbus* sp. which is thought to be only 2-3 years. Thus 2 consecutive breeding failures would pose major threat to population, while 3 consecutive years with no breeding could extirpate the *Barbus* population from this reach before any management actions could be taken.
Season:	Dry season / low flows in Spring (September or October) when all habitats can be effectively sampled with an electro-fisher. Sampling should preferably be undertaken before any significant floods have come through that Spring/Summer. (Note: The most effective baseline EWR survey was conducted in September 2011)
Location:	At the EWR 1 site. It is important to ensure adequate sampling of all available habitats, including undercut banks, overhanging vegetation, fast-shallow & fast-deep (over bedrock/cobble/boulder substrates) and slow shallows with vegetation.
Sampling method:	Perform at least electro-fishing (preferable SAMUS applied by wading) for a minimum time of 60 minutes at the EWR site.

EcoSpecs and TPCs are shown in **Table 11.10** below. Note that ind is used for individual.

Table 11.10: Fish EcoSpecs and TPCs for EWR 1 (Xura River)

RANK	METRIC	PES A/B			
		EWR SITE			
		INDICATOR SPP.	ECOSPECS	TPC (Biotic)	TPC (Habitat)
1	Species richness	BANO, AMOS	Two of the expected (under reference conditions) 3 indigenous fish species were sampled during the 2 baseline (EWR) surveys. AMAR probably very scarce - if present this far upstream	BANO absent during any survey or present at <0.4 ind/min or AMOS absent for 2 consecutive surveys when habitat can be sampled efficiently (AMOS relatively scarce and is difficult to sample effectively).	Loss in diversity, abundance and condition of velocity-depth categories and cover features.
2	Population structure	BANO	During baseline (EWR) surveys at least 2 age classes (both adults and juveniles) of BANO were sampled at 2.5 individuals per minute (September 2011) using a SAMUS electro-fisher (wading). However CPUE was lower in Feb 2012 survey at 0.5 ind/min.*	Only adult fish at less than 0.4 individual per minute sampled at the site during low flows in Spring, when habitat can be sampled efficiently and using an electro-fisher and breeding should have already occurred.	Loss in diversity, abundance and condition of velocity-depth categories and cover features.
3	Flowing (FD and FS) Habitats (flow alteration),	AMOS	AMOS was sampled at 0.07 ind/min* in Sept 2011, but none sampled in February 2012 survey	AMOS absent during 2 consecutive surveys	Reduced suitability (abundance & quality) of FS habitats (i.e. decreased flows, increased zero flows), combined with increased sedimentation of riffle/rapid substrates.
3	Cover: Overhanging vegetation	BANO	BANO was abundant in Sept 2011 survey (2.5 ind/min) and metric provides important cover for both young and adults	BANO captured using electro-fisher at less than 0.4 individual per minute at the site during low flows in Spring, when habitat can be sampled efficiently and using an electro-fisher.	Significant loss of overhanging vegetation due to overgrazing, cattle trampling, bank collapse, sedimentation, reduced flows.
3	Cover: Substrate	AMOS, BANO	Both BANO and AMOS were found to be abundant under boulders and rocks which were not embedded.	BANO captured using electro-fisher at less than 0.4 individual per minute and AMOS absent during 2 consecutive surveys at the site during low flows in Spring, when this habitat can be sampled efficiently.	Reduced suitability (abundance & quality) of substrate habitat due to increased sedimentation and embeddedness of rocks and boulders due to increased sedimentation of riffle/rapid substrates.

RANK	METRIC	PES			
		EWR SITE			
		INDICATOR SPP.	ECOSPECS	TPC (Biotic)	TPC (Habitat)
3	Aquatic macrophytes/ Instream Vegetation	BANO	Instream and marginal vegetation used by BANO as spawning substrate and productive nursery areas for larvae	Both adult and sub-adult BANO captured using electro-fisher at less than 0.4 individual per minute at the site during low flows in Spring, when habitat can be sampled efficiently and using an electro-fisher.	Reduced abundance or accessibility of instream and marginal vegetation due to overgrazing, sedimentation and cattle-trampling and reduced flows
4	Tolerance: Modified physico-chem	AMOS, BANO	Two species (BANO & AMOS) are moderately tolerant, but high temperatures and (probably) low DO levels during low flows in mid-summer considered to be problematic	Low numbers (<0.4 ind/min) of BANO captured in mid to late summer may be due to poor water quality exacerbated by low flows and high temperatures	Decreased water quality -mainly low DO
4	SS habitats	BANO	This metric provides important habitat for both young and adult barbs. BANO was abundant in these habitats in Sept 2011 survey (2.5 ind/min) and reduced numbers (0.5 ind/min) in February 2012.	BANO captured at less than 0.4 ind/min with electro-fisher in Spring when habitat can be sampled effectively	Significant change in SS habitat quality and/or quality (i.e. increased flows, altered seasonality, increased sedimentation of slow habitats).
5	Alien fish species	any alien/ introduced spp.	No alien fish species sampled during the baseline fish surveys	Presence of any alien/introduced species at site	N/A

f) Macroinvertebrates

This section of the report was authored by Dr Mandy Uys of Laughing Waters, who served as the macroinvertebrate specialist for the study.

Available data

Available SASS5 field and reference data collected at or near Site EWR 1 are summarised in **Table 11.11**.

Table 11.11: Summary of available macroinvertebrate data for EWR 1

MRU	Xura 1		
River	**Xura**		**Ntafufu**
Site	EWR1		
Ecoregion L II	16.03		31.01*
Reference	This study		DWA:EC RHP
Date	13.09.2011	2.2012	04.11.2004
Flow (m3/s)	0.16	0.12	Medium
Turbidity	Low		Low
Biotopes sampled	SIC, SOOC, MVIC GSM		SIC, SOOC, MVOOC, GSM
IHAS	70%		78%
SASS5 Score	160	187	213
No Taxa	25	29	34
ASPT	5.4	6.4	6.3
PES Category (A-F)	89.97%	A/B	Not provided
* neighbours ER 16.03			

** DWA: EC RHP refers to data collected by the DWA Eastern Cape office during routine River Health Programme (RHP) monitoring.*

Indicator taxa

The macroinvertebrate taxa in **Table 11.12**, arranged in order of increasing SASS5 score and sensitivity to water quality deterioration, were selected as monitoring indicators for EWR 1. Their velocity and biotope preferences are rated at a preliminary level on a scale of 0 (low) to 5 (very high) (Thirion, 2007).

Table 11.12: Indicator taxa for EWR 1, and their velocity, biotope and water quality preferences

	SASS5 Score	VELOCITY PREFERENCE				BIOTOPE PREFERENCE					WATER QUALITY PREFERENCE
		Preference increases 0 - 5									
Taxon		< 0.1	0.1-0.3	0.3-0.6	> 0.6	BEDROCK	COBBLES	VEG	GSM	WATER	QUALITY
Trichorythidae	**9**	0	1	1	4	1	4	1	0	0	MODERATE
Leptophlebiidae	**9**	3	2	2	1	1	3	2	0	0	MODERATE
Psephenidae	**10**	0	1	3	4	1	4	1	0	0	MODERATE
Athericidae	**10**	0	1	2	2	1	4	1	1	0	MODERATE
Perlidae	**12**	1	1	1	5	1	4	1	0	0	HIGH
Baetidae >2spp	**12**	2	2	2	2	2	2	2	2	1	HIGH
Heptageniidae	**13**	1	1	3	2	1	4	1	0	0	HIGH

EcoSpecs and TPCs

The Invertebrate PES at EWR 1 was an A/B category. The overall Ecostatus was a B category. The EcoSpecs and TPCs for the PES are provided in **Table 11.13**. These are based on the assumption that sampling will be conducted in maintenance years, during early to mid-summer, preferably in the late dry or early wet season and at flows of *at least* 0.1 m^3/s (present day Wet Season low flow value at which invertebrate stress = 5; Dry Season low flow value at which invertebrate stress = 2). At flows in the vicinity of 0.15 m^3/s, results will be comparable to baseline data.

Table 11.13: Ecospecs and TPCs for EWR 1

EcoSpecs: PES	TPCs
SASS5 Score > 160	SASS5 Score < 150
ASPT > 5.2	ASPT < 5
MIRAI Score > 82%	MIRAI Score < 75%
Indicator Taxa	
Primary determinant:	
At least 4 of 7 indicator taxa present.	Three or more indicator taxa absent.
▪ **Detailed determinants:**	**And/or up to four of the following conditions:**
1. Heptageniidae present (B abundance)	Heptageniids absent (or individuals only) on two or more consecutive surveys.
2. Perlidae present in at least one of two consecutive surveys (A abundance)	Perlidae absent on two or more consecutive surveys.
3. Baetidae >2 spp present (B abundance)	Baetidae < 2 spp on any one survey.
4. Athericidae present in at least one of two consecutive surveys (individual or A abundance).	Athericidae absent on two or more consecutive surveys
5. Psephenidae present in at least one of two consecutive surveys (individual or A abundance).	Psepheniidae absent on two or more consecutive surveys.
6. Leptophlebiidae present (B abundance).	Leptophlebiidae absent (or individuals only) on two or more consecutive surveys.
7. Tricorythidae present (A abundance).	Tricorythidae absent (or individuals only) on two or more consecutive surveys.

The Biophysical TPCs are set only for EWR 1 and relate to the water quality environment and hydraulic habitat which create the invertebrate environment (**Table 11.14**). This is desirable but not essential information, although it will assist in the interpretation of Invertebrate data. Where 'red flags' are observed (i.e. initial conditions are not met), a second monitoring visit should be conducted within 2 weeks of the first, in consultation with relevant DWA officials who can provide approximate flow data for EWR 1, sourced from the abstraction weir gauge.

Table 11.14: Biophysical TPCs for EWR 1

BIOPHYSICAL TPCs: EWR 1		
	INITIAL CONDITIONS (Red Flags)	**CONDITIONS AT SECOND VISIT**
WATER QUALITY	Degradation in water quality to a B/C PES	
HYDROLOGY	▪ Absence of velocity class >6m^3/s for longer than a week during Wet Season Maintenance monitoring period. ▪ Absence of velocity class 3-6m^3/s for longer than a week during Wet Season Maintenance monitoring period.	
INSTREAM HABITAT	Loss of the undersurface of approximately half of coarse substrates (cobbles and rocks) due to armouring of the bed and 'packing' of the cobbles.	Same for all
MARGINAL VEGETATION	Exposure of the root zone of > 50% of marginal and instream vegetation species due to scour. Loss of >50% of instream and marginal vegetation (assess from fixed point photography) Less than 5cm inundation of marginal and instream vegetation during Wet Season low flows.	

Monitoring recommendations for EWR 1 and 2

Monitoring recommendations for both sites for macroinvertebrates are shown in **Table 11.15**.

Table 11.15: Macroinvertebrate monitoring recommended for EWR 1 and 2

Season	Early to mid-Summer; late Dry to early Wet Season (October/ November)
Frequency	Once yearly. Should TPCs be noted during first visit, a second visit within 1-2 weeks (dependent on flow conditions) should be conducted to confirm the TPCs and investigate further.
Location	At EWR 1 and EWR 2 (a 50-100 m long section at site). A further monitoring point should be set up some distance downstream of the abstraction weir to assess change in this section.
Method	SASS5, all available habitats, with manual investigation of habitats included (e.g. hand picking)
Additional monitoring	Fixed photo point monitoring (at a riffle or rapid area) to capture at least: - Channel and Bank condition - Instream and Marginal Vegetation state and extent of inundation - Water clarity - Algal cover - Depth of flow over coarse substrates (cobbles/ bedrock) - Turbulence and extent of white water in rapids
	Standard water quality monitoring, i.e. pH, DO, electrical conductivity, temperature

11.2.2 EWR 2 (Msikaba River): Ecospecs and TPCs

The EcoSpecs and TPCs derived from all available data and refined from the *Ecological Reserve Study* are provided below.

a) Hydrology

The output from the Desktop Reserve Model (DRM) – **Table 9.6** – serves as the EcoSpecs for EWR 2.

b) Water quality

EcoSpecs and TPCs are shown in **Table 11.16** and **Table 11.17** respectively and are linked to the present state water quality state as shown in **Table 7.3** and the integrated water quality category as produced by the PAI model.

Table 11.16: Water Quality EcoSpecs for EWR 2 (Msikaba River)

River: Msikaba		EWR: 2	Monitoring site: T6H004Q01 – modified for downstream impacts
Water quality metrics		**ECOSPEC**	
Inorganic salts*	$MgSO_4$	The 95th percentile of the data must be ≤ 16 mg/L.	
	Na_2SO_4	The 95th percentile of the data must be ≤ 20 mg/L.	
	$MgCl_2$	The 95th percentile of the data must be ≤ 15 mg/L.	
	$CaCl_2$	The 95th percentile of the data must be ≤ 21 mg/L.	
	NaCl	The 95th percentile of the data must be ≤ 45 mg/L.	
	$CaSO_4$	The 95th percentile of the data must be ≤ 351 mg/L.	
Physical variables	Electrical conductivity	The 95th percentile of the data must be ≤ 42.5 mS/m.	
	pH	The 5th and 95th percentiles of the data must range from 4.5 to 8.0.	
	Temperature	Natural temperature range.	
	Dissolved oxygen	The 5th percentile of the data must be ≥ 8.0 mg/L.	
	Turbidity	Vary by a small amount from the natural turbidity range; minor silting of instream habitats acceptable.	
Nutrients	TIN	The 50th percentile of the data must be ≤ 2.5 mg/L.	
	PO_4-P	The 50th percentile of the data must be ≤ 0.125 mg/L.	
Toxics		The 95th percentile of the data must be within the Target Water Quality Range (TWQR) as stated in DWAF (1996).	

** To be generated using TEACHA when the TPC for Electrical Conductivity is exceeded or salt pollution expected.*

Table 11.17: Water Quality TPCs for EWR 2 (Msikaba River)

River: Msikaba		EWR: 2	Monitoring site: T6H004Q01 – modified for downstream impacts
Water quality metrics		**TPC**	
Inorganic salts*	$MgSO_4$	The 95th percentile of the data must be 13 – 16 mg/L.	
	Na_2SO_4	The 95th percentile of the data must be 16 – 20 mg/L.	
	$MgCl_2$	The 95th percentile of the data must be 12 – 15 mg/L.	
	$CaCl_2$	The 95th percentile of the data must be 17 – 21 mg/L.	
	NaCl	The 95th percentile of the data must be 36 – 45 mg/L.	
	$CaSO_4$	The 95th percentile of the data must be 280 – 351 mg/L.	
Physical variables	Electrical conductivity	The 95th percentile of the data must be 34 – 42.5 mS/m.	
	pH	The 5th and 95th percentiles of the data must be <4.7 and >7.8.	
	Temperature	Small deviation from the natural temperature range.	
	Dissolved oxygen	The 5th percentile of the data must be 8.2 – 8.0 mg/L.	

River: Msikaba		EWR: 2	Monitoring site: T6H004Q01 – modified for downstream impacts
Water quality metrics		**TPC**	
	Turbidity	Moderate changes to the catchment land-use resulting in temporary unnaturally high sediment loads and high turbidities.	
Nutrients	TIN	The 50th percentile of the data must be 2.0 – 2.5 mg/L.	
	PO_4-P	The 50th percentile of the data must be 0.1 – 0.125 mg/L.	
Toxics		The 95th percentile of the data must be within the Chronic Effects Value (CEV) as stated in DWAF (1996).	

** To be generated using TEACHA when the TPC for Electrical Conductivity is exceeded or salt pollution expected.*

Monitoring should strive to include the following parameters:

- Temperature, dissolved oxygen, turbidity/clarity – little data exists for these parameters.
- Nutrients, i.e. ortho-phosphate and Total Inorganic Nitrogen (TIN). Note that site-specific data were not available for this site. A database of nutrient information should therefore be generated and the accuracy of the EcoSpec and TPCs assessed.
- Diatoms, as they have proved to be a useful indicator of water quality.

c) Riparian vegetation

Table 11.18 shows the EcoSpecs and TPCs for riparian vegetation at EWR 2. Note that the majority of the current baseline values are within range of the proposed EcoSpecs for riparian vegetation, however impacts (particularly in the upper zone of EWR 2) linked to the high alien plant densities, are a matter for concern.

Table 11.18: EcoSpecs and TPCs relating to riparian vegetation EWR 2

Colour coding in the table below refers to:

EcoSpec	TPC	Baseline (measured)	PES C

Ecological Category	Perennial Exotics (% aerial cover)	Reeds (% aerial cover)	Riparian Woody (% aerial cover)	Terrestrialisation (% aerial cover)
Marginal Zone				
A	0	0-2	0-2	0
A/B	1-5			0
B	5-10	3-5	2-5	0
B/C	10-15			0
C	15-20	5-10	5-10	0
C/D	20-30	>10	10-15	0
D	30-50		>15	1-5
D/E	50-60			5-10
E	60-70			10-15
E/F	70-80			15-20
F	>80			>20
Lower Zone				
A	0	0-2	0-2	0
A/B	1-5			0
B	5-10	3-5	2-5	0
B/C	10-15			1-2
C	15-20	5-10	5-10	2-5
C/D	20-30	>10	10-15	5-15
D	30-50		>15	15-20
D/E	50-60			20-30
E	60-70			30-40
E/F	70-80			40-50
F	>80			>50
Upper Zone				
A	0		2-5	0-5
A/B	1-5		5-10	5-10
B	5-10		10-15	10-15
B/C	10-15		15-20	15-20
C	15-20		20-30	20-30
C/D	20-30		>30	30-40
D	30-50			40-50
D/E	50-60			50-60
E	60-70			60-70
E/F	70-80			70-80
F	>80			>80

d) Fish

Fish EcoSpecs and TPCs for EWR 2 are shown in **Table 11.19**.

Table 11.19: Fish EcoSpecs and TPCs for site EWR 2 (Msikaba River)

RANK	METRIC	PES A/B			
		EWR SITE			
		INDICATOR SPP.	ECOSPECS	TPC (Biotic)	TPC (Habitat)
1	Population structure	BANO	During baseline (EWR) surveys at least 2 age classes (both adults and juveniles) of BANO were sampled at 5.5 individuals per minute (September 2011) and 1.9 ind/min in Feb 2012 survey - using a SAMUS electro-fisher (wading).	Only adult fish at less than 1.0 ind/min sampled at the site during low flows in Spring, when habitat can be sampled efficiently and using an electro-fisher and breeding should have already occurred.	Loss in diversity, abundance and condition of velocity-depth categories and cover features.
2	Cover: Overhanging vegetation	BANO	BANO was abundant in both Sept 2011 survey (5.0 ind/min) and February 2012 survey (1.9 ind/min) and this metric provided important cover for both young and adults	BANO captured using electro-fisher at **less than 1.0** individual per minute at the site during low flows in Spring, when habitat can be sampled efficiently and using an electro-fisher.	Significant loss of overhanging vegetation due to overgrazing, cattle trampling, bank collapse, sedimentation, reduced flows.
2	Cover: Substrate	BANO	BANO were found to be abundant under boulders and rocks which were not embedded.	BANO captured using electro-fisher at less than 1.9 individual per minute at the site during low flows in Spring, when this habitat can be sampled efficiently.	Reduced suitability (abundance & quality) of substrate habitat due to increased sedimentation and loss of un-embedded rocks and boulders due to increased silting up of riffle/rapid substrates.
2	Aquatic macrophytes/ Instream Vegetation	BANO	Instream and marginal vegetation used by BANO as spawning substrate and productive nursery areas for larvae	Both adult and sub-adult BANO captured using electro-fisher **at less than 1.0** individual per minute at the site during low flows in Spring, when habitat can be sampled efficiently and using an electro-fisher.	Reduced abundance or accessibility of instream and marginal vegetation due to overgrazing, sedimentation and cattle-trampling and reduced flows
3	Tolerance: Modified physico-chem	BANO	BANO is moderately tolerant, but high temperatures and (probably) low DO levels during low flows in mid-summer may become to be problematic	Low numbers (<1.0 ind/min) of BANO captured in mid to late summer may be due to poor water quality exacerbated by low flows and high temperatures	Decreased water quality -mainly low DO

RANK	METRIC	PES			
		EWR SITE			
		INDICATOR SPP.	ECOSPECS	TPC (Biotic)	TPC (Habitat)
4	SS habitats	BANO	BANO was abundant in these habitats in Sept 2011 survey (5.0 ind/min) and metric provides important habitat for both young and adults	BANO captured at less than 1.0 ind/min with electro-fisher in Spring when this habitat can be sampled effectively	Significant change in SS habitat quality and/or quality (i.e. increased flows, altered seasonality, increased sedimentation of slow habitats).
5	Alien fish species	any alien fish or introduced spp.	No alien or introduced fish species sampled during the baseline fish surveys	Presence of any alien/introduced species at site	N/A

e) Macroinvertebrates

Available data

Available quantitative data on aquatic macroinvertebrates in the Msikaba River are summarised in **Table 11.20**.

Table 11.20: Summary of available invertebrate data for EWR 2

River	Msikaba		Msikaba	Mtamvuna
Site	EWR2			
Details			Upstream confluence with Xura	
Ecoregion L II	17.01		17.01	17.01
Quaternary	T60G		T60F	T40E
Reference	This study		DWA:EC RHP	DWA: EC RHP
Date	13.09.2011	08.02.2012	03.11.2004	01.11.2004
Flow (m3/s)	1.18	1.27	No Info	Medium
Turbidity	Low		No Info	High
Biotopes sampled	SIC, SOOC, MVIC, MVOOC, GSM		SIC, MVOOC, GSM	SIC, SOOC, MVIC, MVOOC, GSM
IHAS	70%		64%	73%
SASS5 Score	129	178	189	224
No Taxa	19	27	29	36
ASPT	6.8	6.6	6.5	6.22
PES Category (A-F)	83.1% (B)		NA	NA

** DWA: EC RHP refers to data collected by the DWA Eastern Cape office during routine River Health Programme monitoring.*

Indicator taxa

The taxa shown in **Table 11.21** were collected in one or both of the field samples and are considered suitable indicator taxa for the Ecospecs and TPCs.

Table 11.21: Indicator taxa for EWR 2, and their velocity, biotope and water quality preferences

	SASS5 Score	VELOCITY PREFERENCE				BIOTOPE PREFERENCE					WATER QUALITY PREFERENCE
		Preference increases 0 - 5									
Taxon		**<0.1**	**0.1-0.3**	**0.3-0.6**	**>0.6**	**BEDROCK**	**COBBLES**	**VEG**	**GSM**	**WATER**	**QUALITY**
Leptophlebiidae	9	3	2	2	1	1	3	2	0	0	MODERATE
Trichorythidae	9	0	1	1	4	1	4	1	0	0	MODERATE
Calopterygidae	10	1	3	1	0	0	1	3	1	0	MODERATE
Chlorocyphidae	10	2	3	1	0	1	4	1	0	0	MODERATE
Philopotamidae	10	0	1	2	3	1	4	1	1	0	MODERATE
Psephenidae	10	0	1	3	4	1	4	1	0	0	MODERATE
Athericidae	10	0	1	2	2	1	4	1	1	0	MODERATE
Perlidae	12	1	1	1	5	1	4	1	0	0	HIGH
Baetidae >2spp	12	2	2	2	2	2	2	2	2	1	HIGH
Heptageniidae	13	1	1	3	2	1	4	1	0	0	HIGH

EcoSpecs and TPCs

The Invertebrate PES at EWR 2 was a B. The overall Ecostatus was a B/C category. The EcoSpecs and TPCs for the invertebrate PES are provided below. These are based on the assumption that sampling will be conducted in maintenance years, during early to mid-summer (October/November), i.e. late Dry or early Wet season and at flows of at least 0.6 m^3/s (present day Wet Season low flow value at which invertebrate stress = 5; and the Dry Season low flow value at which invertebrate stress = 2). At a flow of around 1.2 m^3/s, results will be comparable to baseline data. The EcoSpecs and TPCs were defined for EWR 2 and are presented in **Table 11.22**.

Table 11.22: Ecospecs and TPCs for EWR 2

EcoSpecs	TPCs
SASS5 Score > 120	SASS5 Score < 115
ASPT > 6.2	ASPT < 6.2
Indicator Taxa	
Preliminary determinant:	
At least 6 out of 10 indicator taxa present.	Less than 6 indicator taxa present
Detailed determinants:	**And/or up to four of the following conditions:**
1. Perlidae present in at least one of two consecutive samples	Perlidae absent in one of two consecutive samples.
2. Heptageniidae in at least one of two consecutive samples (A-B abundance)	Heptageniidae absent.
3. Baetidae >2 spp present (A-B abundance)	Baetidae 2 spp or less in two consecutive samples.
4. Athericidae present.	Athericidae absent.
5. Philopotamidae present in at least one of two consecutive samples.	Philopotamidae absent in two consecutive samples.
6. Chlorocyphidae present in at least one of two consecutive samples.	Chlorocyphidae absent in two consecutive samples.
7. Calopterygidae present in at least one of two consecutive samples.	Calopterygidae absent in two consecutive samples.
8. Psephenidae present in at least one of two consecutive samples.	Psephenidae absent in two consecutive samples.
9. Tricorythidae present (A-B abundance).	Tricorythidae absent.
10. Leptophlebiidae present (A-B abundance).	Leptophlebiidae absent.

12 REFERENCES

Birkhead, A., Uys, A., Scherman, P-A., Bok, A., Colloty, B. and Chalmers, R. 2013. *Review and update of the 1999 EIS/PES of South African rivers, including expansion to priority tributaries and wetlands, according to quaternary catchments for the Water Management Areas 12 & 15.* Prepared for the Department of Water Affairs and the Water Research Commission, South Africa. WRC Project No. K5/2045.

Brown, C. and King, J. 2001. *Environmental flow assessment for rivers. A summary of the DRIFT process.* Southern Waters information Report No 01/00.

Bunn, S.E. and Arthington, A.E. 2002. *Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity*. Environmental Management 30, 492–507.

Department of Water Affairs and Forestry. 1996. *South African Water Quality Guidelines. Volume 7: Aquatic Ecosystems*. Department of Water Affairs and Forestry, Pretoria, South Africa.

Department of Water Affairs and Forestry. 1999. *Resource directed measures for the protection of water resources.* Volume 3: River ecosystems, version 1.0.

Department of Water Affairs and Forestry. 2008a. Comprehensive *Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Inkomati Water Management Area, Mpumalanga. Sabie and Crocodile Systems: Resource Unit Delineation.* Prepared by Water for Africa, authored by Louw, MD. Report no. 26/8/3/10/12/006.

Department of Water Affairs and Forestry. 2008b. Methods *for determining the Water Quality component of the Ecological Reserve.* Report prepared for Department of Water Affairs and Forestry, Pretoria, South Africa by Scherman Consulting.

Department of Water Affairs. 2009a. *Resource Directed Measures: Reserve Determination studies for selected surface water, groundwater, estuaries and wetlands in the Outeniqua catchment: Ecological Water Requirements Study. Riverine RDM Report, Volume 1: Assessment.* Edited by Louw, MD and Koekemoer, S for Scherman Colloty & Associates. Report no. RDM/K40-50/00/CON/0607, Volume 1.

Department of Water Affairs. 2009b. *Resource Directed Measures: Comprehensive Reserve determination study of the Integrated Vaal River System. Upper Vaal Water Management Area Technical Component: EWR Scenario Report: Volume 1.* Report produced by Koekemoer Aquatic Services and Rivers for Africa. Authored by Louw, D. Report no: RDM/ WMA8 C000/01/CON/0807.

Department of Water Affairs. 2013. *Feasibility study for augmentation of the Lusikisiki Regional Water Supply Scheme: Water resources assessment. Appendix K: Ecological Analysis*. Report No. P WMA 12/T60/00/3711.

Hill Kaplan Scott. 1986. *Lusikisiki Regional Water Supply Scheme: Preliminary Report*. Report No. 6671.

Hughes, D.A. and Forsyth, D.A. 2006. *A generic database and spatial interface for the application of hydrological and water resource models.* Computers and Geosciences 32, 1389-1402.

Iversen, T.M., Madsen, B.L. and Bøgestrand, J. 2000. *River conservation in the European Community, including Scandinavia.In: "Global Perspectives on River Conservation: Science Policy and Practice"*, Edited by P.J. Boon, B.R. Davies and G.E. Petts, John Wiley & Sons Ltd.

IWR Source-to-Sea (eds). 2004. *A Comprehensive EcoClassification and Habitat Flow Stressor Response Manual.* Prepared for IWQS: DWAF, Project no: 2002-148.

King, J.M. and Louw, D. 1998. *Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology*. Aquatic Ecosystem Health and Management 1: 109-124.

Kleynhans, C.J., Louw, M.D., Thirion, C., Rossouw, N.J., and Rowntree, K. 2005. *River EcoClassification: Manual for EcoStatus determination (Version 1).* Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. KV 168/05.

Kleynhans, C.J. and Louw, M.D. 2007. *Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2)*.

Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT329-08.

Kleynhans, C.J. 2007. *Module D: Fish Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2)*. Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 330/08.

Kleynhans, C.J., Mackenzie, J and Louw, M.D. 2007. *Module F: Riparian Vegetation Response Index. In River EcoClassification: Manual for EcoStatus Determination (version 2)*. Water Research Commission Report No. TT 333/08. Joint Water Research Commission and Department of Water Affairs and Forestry report, Pretoria, South Africa.

Kleynhans, C.J., Louw, M.D., and Graham, M. 2009. *Module G: EcoClassification and EcoStatus determination in River EcoClassification: Index of Habitat Integrity (Section 1, Technical manual)*. Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT330/08.

Louw, M.D. and Koekemoer, S. (editors). 2010. *Deliverable 12. Volume 2: Support to Volume 1 in terms of Monitoring: EcoSpecs and Thresholds of Potential Concern.* Produced for WRP as part of Support to Phase II ORASECOM Basin Wide Integrated Water Resources Management Plan.

Noss, R.F. 1990. *Indicators for monitoring biodiversity: a hierarchical approach*. Conservation Biology 4:355-364.

O'Keeffe, J.H., Hughes, D.A. and Tharme, R. 2002. *Linking ecological responses to altered flows, for use in enviromental flow assessments: the Flow Stress-Response method*. Proceedings of the International Association of Theoretical and Applied Limnology, 28, 84-92.

Rowntree, K.M. (2013). *Module B: Geomorphology Driver Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2)*. Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT551/13.

Thirion, C. 2007. *Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2)*. Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT330/08.